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A Multi-task Ice Data Analysis System

Summary Report

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A MULTI TASK ICE DATA ANALYSIS SYSTEM
SUMMARY REPORT

prepared for the
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Montreal, Quebec

prepared by
INTERA TECHNOLOGIES LTD.
Calgary, Alberta

August 1985

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PROJECT TEAM:

The project team for INTERA Technologies Ltd. was composed of:

Dr. R. Lowry
Dr. D.R. Inkster
Mr. G. McAvoy
Mr. J. DeAlmeida
Mr. M. Fruhwirth
Mr. A. Schmidt
Mr. D. Maulsby
Mr. H. Lukatela
Mr. R. DuWors

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17 Abstract

The objective of the MIDAS (Multi-Task Ice Data Analysis System) program was to develop a conceptual design for a shipboard ice navigation system. MIDAS is an integrated facility that utilized remotely sensed data for close-range hazard detection and for strategic and tactical ice navigation. This system makes it possible to route a vessel through an ice field minimizing or avoiding contact with ice. During the course of this project, three field operations were undertaken to provide the necessary information for a system design. These operations were carried out on-board the Arctic class one carrier, the M.V. Arctic, a facility provided by Canarctic Shipping Company Ltd. The analysis of these operations resulted in a detailed user requirements document and functional specification for MIDAS. A prototype hardware design for this system is also described.

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16 Agent de projet — CDT
M. Audette

17 Résumé

Ce rapport fait le point sur le programme d'étude d'un système multifonctionnel d'analyse des données glacielles (MIDAS) qui serait en même temps un système embarqué d'aide à la navigation dans les glaces. De par sa conception, MIDAS est un système intégré qui assure, à partir des données fournies par différents moyens de télédétection, le repérage des glaces flottantes pouvant présenter un danger immédiat et la détermination de la route à suivre optimale tant à court qu'à long terme. Il permet donc aux navires qui en sont équipés de franchir un secteur chargé de glaces, sans heurter ou en heurtant le moins possible ces dernières. Dans un premier temps, les chercheurs ont recueilli des données sur les conditions de navigation dans les glaces, à l'occasion de trois périples à bord de l'Arctic, un minéralier de cote arctique, propriété de Canarctic Shipping Company Ltd. L'analyse de ces données a permis l'élaboration du programme des besoins des usagers et d'un cahier des charges fonctionnel du système envisagé. Le rapport décrit également les éléments matériels d'un prototype du système.

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FOREWORD

This report describes the development of MIDAS (Multi-task Ice Data Analysis System) - an integrated shipborne facility that utilizes remotely sensed data for close-range hazard detection and for strategic and tactical ice navigation. The core of this system is a marine radar display system and airborne radar display/user workstation. This system makes it possible to selectively route a vessel through an ice-field minimizing contact with the ice encountered and avoiding contact with heavy ice. During the course of the MIDAS program three field experiments were undertaken onboard the M.V. Arctic (Canarctic Shipping Co. Ltd.) to provide the information necessary for a system design. The analysis of these operations resulted in a requirements document and functional specification which is briefly presented. A prototype hardware design for this system is also described.

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1. INTRODUCTION

1.1 Background

The dominant factor in Canada's northern offshore environment is the more or less continuous presence of ice in various forms and concentrations; this has severely restricted marine transportation to the scattered arctic settlements and presents a formidable problem for the operators engaged in offshore drilling activities.

During the fall of 1979, Dome Petroleum's subsidiary, Canadian Marine Drilling (Canmar), was able to extend its drilling season in the Beaufort Sea by making use of Synthetic Aperture Radar (SAR) imagery [1]. The near real-time imagery was made available to an ice strengthened drillship via a VHF data link and provided a "snap-shot-like" view of the ice conditions in the vicinity of the operations. This was then used for icebreaker support and subsequent navigation back to the harbour.

Since that time, the use of remotely sensed data such as SAR and SLAR has expanded rapidly, so that it is now possible for marine operators to obtain reliable, all-weather information on ice conditions and hazards. In fact, a comprehensive study called "REMSCAN" was undertaken by Transportation Development Centre, Transport Canada (TDC), to develop a coordinated approach to the acquisition, processing, and dissemination of the information necessary for safe, efficient marine transporation and other offshore activities in the arctic environment [2].

The Canarctic Shipping Company Limited has also undertaken an extensive research program to develop new techniques for navigating in ice. Canarctic owns and operates the M.V. Arctic, a Canadian-built Class 2 icebreaking bulk carrier. Since 1978, the ship has carried lead/zinc concentrates to Europe from the Nanisivik mine on Baffin Island; Canarctic began the same service from the Polaris mine on Little Cornwallis Island in 1982.

Both Canarctic and INTERA have been working together over the last two years to develop an integrated ice information system to be used on commercial icebreaking ships. Canarctic has pioneered work on ice hazard detection systems and ice navigation techniques using remotely sensed data under a program titled "SINSS" (Shipboard Ice Navigation Support System) [3]. INTERA, through TDC funding, has focused on developing an integrated shipborne system (MIDAS) that uses both airborne radar and marine radar imagery for ice navigation.

1.2 Navigation in Ice

The experience gained by INTERA, Canarctic, Dome and other organizations engaged in Arctic sea operations has shown that real-time ice information, which is available from sources like airborne radars (SAR,SLAR), marine radars, and satellites (IR/visual), can be used for better route planning and tactical navigation by ships in transit. With a knowledge of the ice conditions in an operational region, a ship's master can optimize his route and avoid areas where the risk of contact with ice or heavy ice is great. The resulting savings in ship operating costs, reduced vessel damage, and improved delivery schedules have proven to be very substantial.

2. SOURCES OF ICE INFORMATION

The data required for navigation in ice can generally be divided into three categories which depend, to some extent, on how these data are utilized. These are:

(1) Strategic information;
(2) Tactical information; and
(3) Close Range Hazard information.

Strategic information generally provides the user with the overall ice, sea and weather conditions that will be encountered within his area of operation.

Tactical information is used to actually change this ship's course from one area to the next. It is information on conditions that might impact the user within a few hours.

Close range hazard information describes the ice features within the immediate vicinity of the user. This would be used to avoid hazards such as floating icebergs in the path of a ship.

Table 1 lists a number of the sources of ice information which can be utilized for navigational purposes. Notice that several of these sources fall into more than one category. Airborne SAR, for example, can be used for strategic planning by mapping large areas on the order of hundreds of kilometres. If the resolution is high enough, this same information can be used for close range hazard avoidance. INTERA's STAR-1 SAR typically images a ground swath 50 km in width and the endurance of the aircraft is such that large areas, such as Baffin Bay or Lancaster Sound, can be mapped during a single mission. This information can then be downlinked to a ship in near real-time. For a 50-km swath width, the resolution of the ground pixels is 12 metres by 12 metres, which is suitable for close range hazard avoidance.

STRATEGIC (100 - 1000 km)	TACTICAL (25 - 200 km)	CLOSE RANGE (0.5 - 50 km)
- interpreted ice charts - Weather forecasts - Satellite; NOAA LANDSAT METEOR - Passive Microwave - SLAR airborne & SAR spaceborne	- SLAR (airborne) - SAR (airborne) - Marine Radar	Marine Radar Sonar Codar (H.F.)

Table 1 Sources of information for ice navigation.

3. THE MIDAS PROJECT

During the course of the MIDAS project, three field operations were undertaken to provide the necessary information for a detailed design. All of these operations were carried out on-board the Arctic-class ore carrier, the M.V. Arctic - a facility provided by Canarctic and judged to be ideal for this study. The analysis of these operations resulted in a detailed user requirements document and specification for MIDAS.

One of the key concepts to emerge from this research is that of an "ice navigation chart". Typically, navigators have charts of the world's oceans; however, what is required for operations in the Arctic is a similar chart showing detailed ice conditions over a fairly large region. This requires information which is superior to what has been available in the past. Features such as old ice and icebergs with sizes in the order of 10 metres should be shown on the chart. Areas of ice rubble, ice build-up and ice compression also need to be shown. Because ice conditions change rapidly, this information must be available in real-time. It has been demonstrated that airborne radar SAR imagery, such as that available from INTERA's STAR-1 provides the right image characteristics and the right level of information to be used as an ice navigation chart. It is also easily interpreted by ship's officers. By staging periodic airborne radar missions, geographically annotated airborne radar data can be telemetered to the bridge of a ship in real-time and then used for ice navigation. The ship's marine radar provides the means of tracking the position of the ship on the SAR imagery when ice conditions have changed.

3.1 MIDAS SYSTEM REQUIREMENTS

The MIDAS system requirements are based on the results of the field operations previously described and a detailed task analysis conducted by INTERA.

3.1.1 Weather and Ice Charts

For strategic level planning, the ice and weather charts currently available from Atmospheric Environment Services and other agencies provide a first level of support (Table 2). However due to the severe communication problems in the Arctic, these products are not always available. Furthermore, the accuracy of the predicted ice conditions is often less than desirable, particularly when conditions are changing rapidly. Therefore, these information products need to be supplemented by other sources for navigating ships.

(1) Data must be timely, i.e. must be available to a navigating ship in near real-time.
(2) Interpretation must be accurate.
(3) Data must be available on standard marine circuits or satellite links to ships operating in the Arctic.

Table 2 Summary of the requirements for ice and weather charts for ships navigating in ice.

3.1.2 Satellite Receivers

A satellite receiver, such as that sold by Muirhead Systems Limited, can be used to receive direct readout real-time satellite imagery from polar orbiting satellites on VHF frequencies. The Muirhead interactive display system receives the automatic picture transmissions from the NOAA 7 and 8 satellites, stores these data on a small computer and displays data on a colour RGB monitor.

The advantage of direct readout systems like Muirhead's is that real-time data are easily received anywhere in the Arctic. The disadvantage of IR/visible satellite data, or course, is that ice information is only available under favourable atmospheric conditions, i.e. when there is little or no cloud cover.

The requirements for such systems are summarized in Table 3.

(1) System must be capable of automatically receiving and storing satellite IR/visible transmissions from polar satellites.
(2) System should allow user to display data with a minimum of effort at full resolution.
(3) Images displayed should be annotated with latitude and longitude information.
(4) Image processing algorithms should be available to enhance and correct raw data where necessary to aid interpretation.

Table 3 Requirements for a real-time satellite receiver station for a shipboard ice navigation system.

3.1.3 Airborne Radar

Due to the problems with reception and the question of reliability with the previous sources of strategic information mentioned, airborne radar is also required for totally reliable support for Arctic operations. Radar is able to extend the data collection window since it is not hampered by cloud cover or darkness. It is real-time, high resolution, relatively inexpensive and can be easily transmitted to a ship in transit.

Side looking airborne radars (SLAR's) have traditionally been used to provide wide area coverage (50-100 km per side) of the Arctic ice. Such systems are operated both by government and by private companies. It has been demonstrated that SLAR imagery can provide valuable information on ice conditions. Ice classification is made on the basis of tone, texture and context of the data.

A summary of the basic requirements for a SLAR system which could be used for ice navigation tasks by a navigating ship is listed in Table 4.

---

(1) Recorded data must be in digital format so that it can be telemetered easily from aircraft to ship.
(2) High quality motion compensation required onboard aircraft to pre-correct data before transmission.
(3) Aircraft should fly at high altitudes (approx. 16,000 ft).
(4) Requires trained operators to ensure radiometric fidelity of data.
(5) System should be operated in narrow swath (25 km per side) mode for unambiguous ice information.
(6) Georeferencing of data would be useful.

Table 4 Basic requirements for a SLAR system to be used for ice navigation.

Experience gained on the M.V. Arctic has shown that a high resolution airborne radar that is capable of making unambiguous ice classification is required for tactical support in difficult ice conditions. INTERA's STAR-1 SAR is such a system, since it achieves a resolution of a few metres. This SAR has excellent radiometric characteristics and shows a much greater consistency of return than SLAR.

The basic requirements for a SAR system which will support ice navigation are summarized in Table 5.

(1) Recorded data must be digital format so that it can be telemetered easily from aircraft to ship.
(2) Data should be precorrected for motion compensation before transmission.
(3) Aircraft should fly at high altitude (10,000 m) for uniform illumination of sea ice.
(4) 12 x 12 m ground pixels required for close tactical navigation in heavy ice.
(5) 24 x 24 m ground pixels adequate for strategic and tactical navigation tasks.
(6) The imagery should be georeferenced to aid ice navigation.
(7) The high resolution radar data must be available to ship's personnel in any easy-to-use format.

Table 5. Basic requirements for a SAR system to be used to support ice navigation.

3.1.4 Marine Radar

A significant problem with using airborne radar imagery for tactical navigation is identifying the ship's position on the imagery. Keeping track of the ship's progress through the ice is also a complex task and generally the only sensor capable of accomplishing these tasks is the ship's own marine radar.

For tactical navigation, marine radar provides the much-needed connection between where the ice is at the time of the ship's passage and where it was when the airborne imagery was collected. By constantly tracking the ship's position in the airborne ice image with the marine radar, the airborne radar imagery can be used to steer the ship and avoid hazards.

For conventional navigation tasks, the marine radar has become the prime source of close tactical and tactical information. From the ice navigation viewpoint, however, its range is too limited for practical route selection. Thus, the main task for the marine radar when in heavy ice has become to locate and track the ship's progress on airborne radar imagery. In the presence of icebergs, or very low concentrations of ice, the target detection capability is of the utmost importance. There are three basic requirements for an ice navigation radar. First, it must be able to detect weak targets at far range. Second, it should be able to detect targets in the presence of both sea clutter and bad weather. These are both aims of conventional radars. Third, and unique to this application, the radar must be capable of making a 'picture' of the ice for comparison with the airborne radar imagery.

The marine radar required for MIDAS is therefore a bright, multi-level display with simple, easily understood controls. The minimum requirements for the marine radar display for MIDAS can be summarized as in Table 6.

---

(1) The system must present marine radar data on a bright TV-type display. This display should refresh in real time and allow an individual image to be frozen on the display for any length of time.

(2) The system should be able to interface with any radar without overriding the normal radar controls.

(3) The system should display both north up and ship's head up radar data.

(4) The image should be displayed with the normal radar ranges of 0.75, 1.5, 3, 6, 12, 24 and 48 n miles.

(5) The display must have at least 2 bits of video display and should have a choice of colour or black and white presentation.

(6) It should have the normal radar signal processing such as STC and FTC available.

(7) The user interface should have controls that are similar to or emulate those of a standard radar. It must be easy to use by ship's crew, ice observers, and those familiar with radar systems.

(8) The system must have a standard computer interface so that data can be shared with other computer systems.

(9) The equipment must be reliable and robust and suitable for mounting on the bridge of a ship.

Table 6 Basic requirements for the marine radar display for an ice navigation system.

There have not been any commercial radar systems available in the past which satisfy all of these requirements; however, new digital systems are just now becoming available which will satisfy some. INTERA is currently investigating these systems and evaluating their suitability for Canarctic.

3.1.5 Future Systems

There are a number of systems currently being developed which will almost certainly play a role in the future MIDAS design. Of prime importance are the European Space Agency SPOT and ERS-1 systems to be used for ocean observations and resource management and the Canadian Radarsat scheduled for launch in 1990. Both of these systems will improve the level of ice information which will be available to a ship operating in the Arctic regions. These systems will have to be carefully studied and the suitability of their data for tactical navigation determined. The main problems are: the limited resolution of the data, the fact that the information may not be available to the ship in near real-time due to the time required for processing, and the communications problem of getting a high quality image product to the ship. From our present research it is clear that any interpreted ice charts made from these data sources are not acceptable for tactical navigation tasks.

4. THE MIDAS DESIGN

There are essentially two tasks to be accomplished by MIDAS. First, a ship must be able to select the optimum route which normally means minimizing the ice encountered, both in quantity and severity. Second, once a route is chosen, the system must be able to show the location of all the exceptional hazards on that route. Figure 1 shows an artist's sketch of a proposed baseline MIDAS system. It consists of the following four components:

1. A system capable of automatically receiving and storing, and interactively displaying airborne radar data. INTERA is now designing and building such a system called STAR-VUE. STAR-VUE is a microcomputer based system which serves as both a receiver and user workstation (Figure 2). Geographically annotated airborne radar data that are telemetered from the aircraft are automatically received and stored on random access media (e.g. magnetic disk) by the system. The received data are in the form of image strips which represent the area covered by individual flights. The images are viewed through adjustable "windows" which can be made to show the area of interest. The user can scan over a large area image at full resolution by keeping the window size small and varying its position. For navigation, at least two windows are used - one to show broad coverage and a second to show fine resolution. Because this is a computer-based system, it has a well-designed user interface and can be used to display other imagery or extracted data from other sources like visual/IR satellite or marine radar.

2. A marine radar display system which is capable of displaying both real-time and "enhanced" marine radar data on bright TV-type displays. The display on the far left of Figure 1 shows a real-time radar display whose main function is to provide an image of the local ice conditions. Several radar manufacturers are now marketing low end radar systems and "repeater" systems with bright TV-type displays which may be suitable for this role. The second display shown is a special purpose unit such as INTERA's Radar Image Display System (RIDS). This system also has a bright display and can be used to archive and display "processed images" from one or more radar systems. The screen update is not necessarily real-time but is under much greater operator control. Because of the great flexibility of the system, a computer terminal is used for its operation.

3. A system or number of systems capable of receiving conventional ice and weather charts and real-time satellite imagery. Because of the communication problems encountered in the Arctic, real-time satellite products are also required for strategic support. A number of commercial systems are available which receive data from the NOAA polar orbiting satellites. The display on the far right of Figure 1 is reserved for such a system.

4. A communications interface between these systems. At the present time, the information communicated between systems is via a human interpreter.

It is INTERA's recommendation that these system operate separately for the present time. Each system requires further development and to be field tested before any substantial integration takes place. "Integration" here means more that a data exchange; it must be an exchange of information between systems that aids navigation ice.

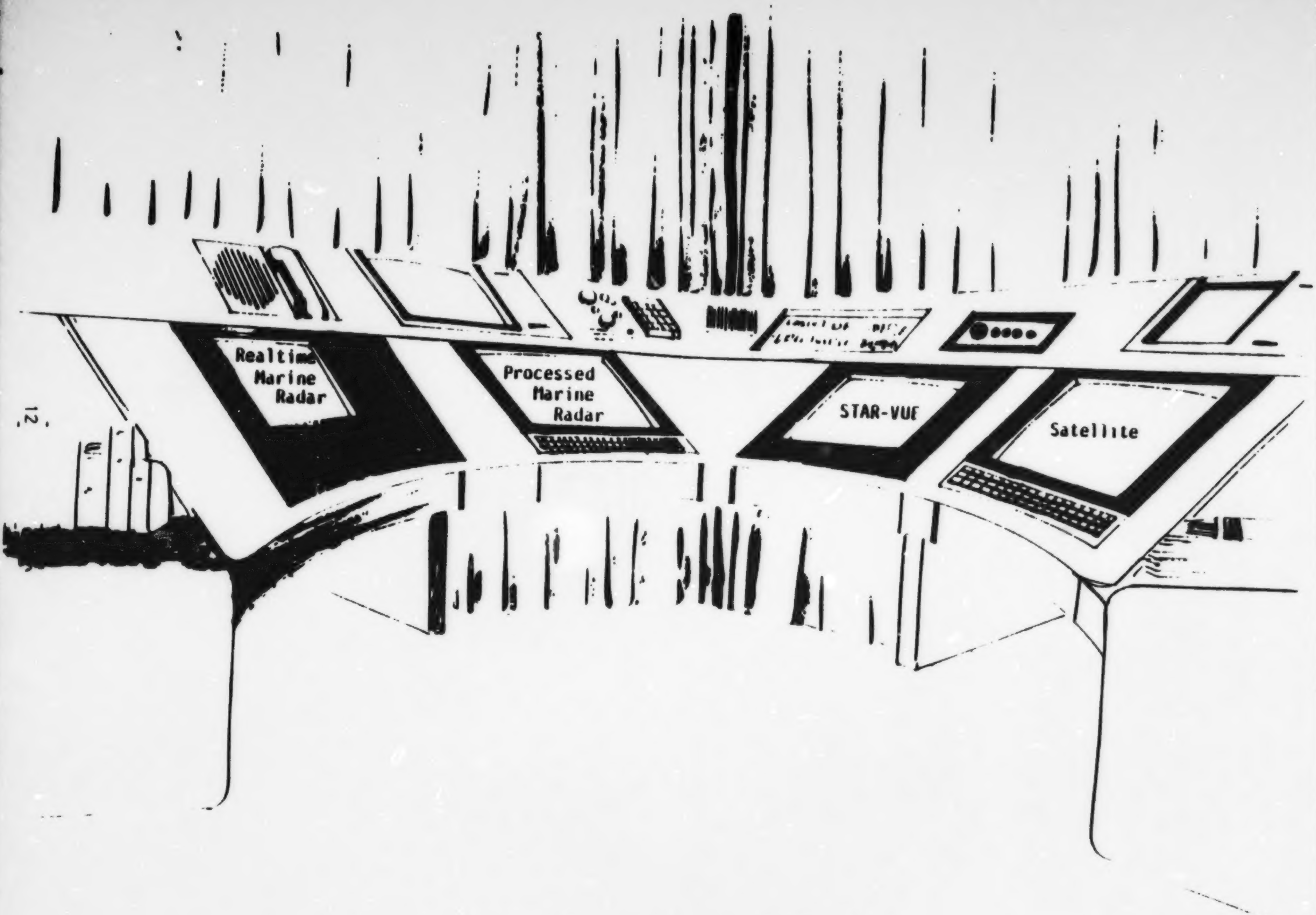
Realtime Marine Radar
Processed Marine Radar
STAR-VUE
Satellite

Figure 1. A MIDAS system which is suitable for shipbased operation.

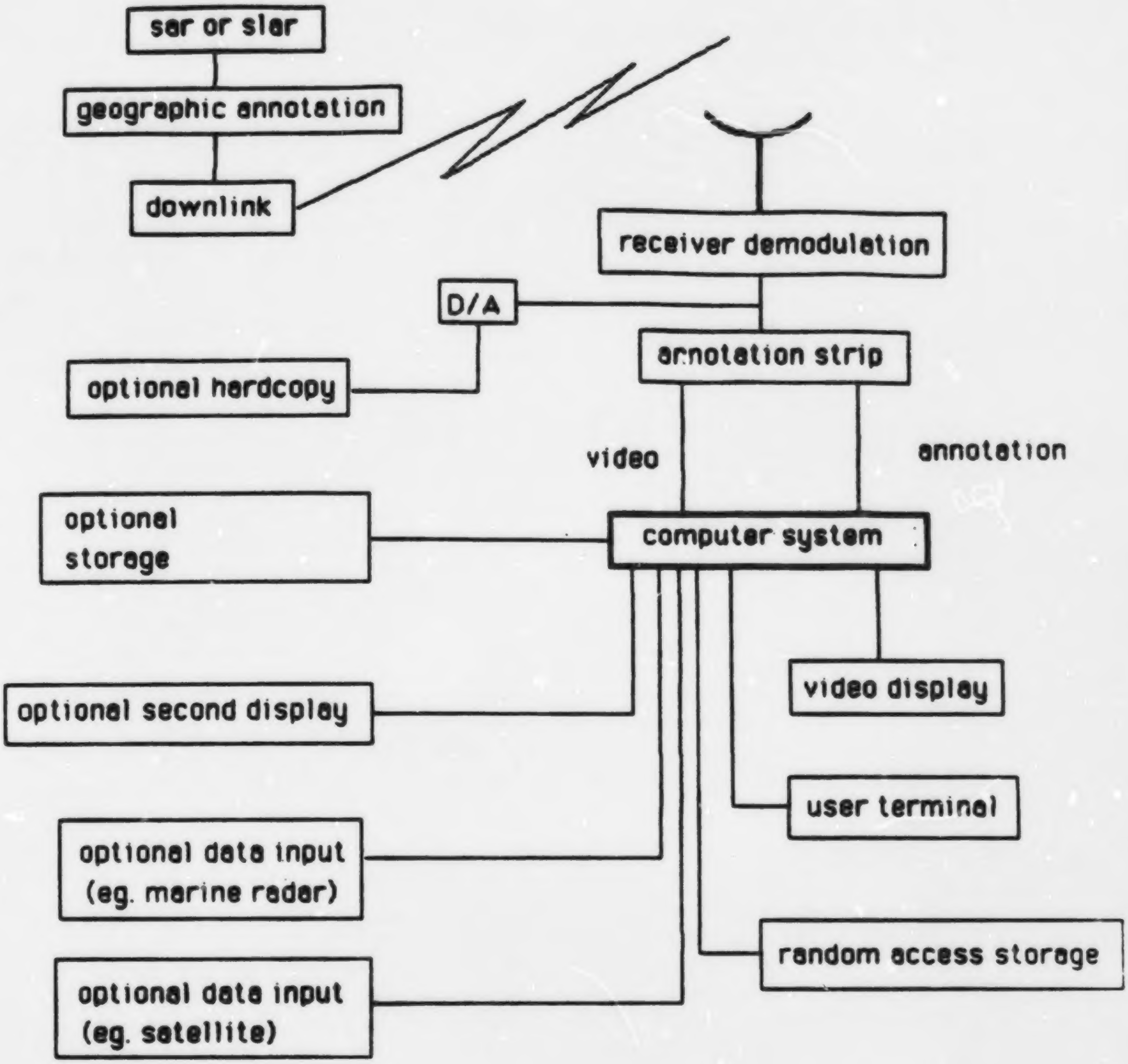
sar or slar
geographic annotation
downlink
receiver demodulation
D/A
annotation strip
optional hardcopy
video
annotation
optional storage
computer system
optional second display
video display
user terminal
optional data input (eg. marine radar)
random access storage
optional data input (eg. satellite)

Figure 2. Base line design of a MIDAS system. Here the downlink receiver and user work station share the same computer system. Such a system should also accept input from data sources like marine radar and satellites. A system incorporating most of these functions, called "STAR-VUE", is now being built by INTERA.

5. MIDAS OPERATION

The following briefly describes how this MIDAS system would operate on an icebreaking ship.

1. The currently available ice and weather charts, supplemented with real-time satellite imagery and other available products, provide the user with a strategic overview of the ice coverage in his area of interest. With this overview the ship's operators are able to plan their overall course, spot areas that require more detailed coverage along their route, and arrange to have these areas covered by a higher resolution sensor (eg. airborne radar).

2. Airborne radar imagery provides the user with the next level of support, which can be either strategic or tactical. The airborne radar data is telemetered to the user via a VHF radio link when the aircraft is within range (200 nm). This information can be real-time imagery or imagery recorded earlier and stored on magnetic media. The airborne radar imagery is received and stored automatically on the ship by a system like INTERA's STAR-VUE. The system is capable of displaying on a video monitor airborne radar imagery of a large area which can be used for route planning as well as a high resolution imagery of a smaller area, which is used along with the marine radar for tactical navigation.

3. The marine radar is displayed on another video monitor and is used to track the movement of the ship on the airborne image display. The marine radar is also the main tool for close hazard avoidance in darkness or during bad visibility and airborne radar (SAR) data are displayed side by side on bright TV type displays with the same approximate resolution and orientation.

6. CONCLUSIONS

The system described here represents a new approach to ice navigation. The successful demonstration of the utility of remotely sensed data for ice navigation has influenced the thinking on marine operations in the Arctic. It has been shown by the M.V. Arctic that it is now possible for smaller class icebreakers and tankers to extend their operations by making use of this new technology. This is an alternative to the conventional thinking which is to build larger, heavier vessels and icebreakers.

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PROJECT TEAM:

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M. Audette

17. Abstract

The objective of the MIDAS (Multi-Task Ice Data Analysis System) program was to develop a conceptual design for a shipboard ice navigation system. MIDAS is an integrated facility that utilized remotely sensed data for close-range hazard detection and for strategic and tactical ice navigation. This system makes it possible to route a vessel through an ice field minimizing or avoiding contact with ice. During the course of this project, three field operations were undertaken to provide the necessary information for a system design. These operations were carried out on-board the Arctic class one carrier, the M.V. Arctic, a facility provided by Canarctic Shipping Company Ltd. The analysis of these operations resulted in a detailed user requirements document and functional specification for MIDAS. A prototype hardware design for this system is also described.

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17. Resume

Ce rapport fait le point sur le programme d'étude d'un système multifonctionnel d'analyse des données glacielles (MIDAS) qui serait en même temps un système embarqué d'aide à la navigation dans les glaces. De par sa conception, MIDAS est un système intégré qui assure, à partir des données fournies par différents moyens de télédétection, le repérage des glaces flottantes pouvant présenter un danger immédiat et la détermination de la route à suivre optimale tant à court qu'à long terme. Il permet donc aux navires qui en sont équipés de franchir un secteur chargé de glaces, sans heurter ou en heurtant le moins possible ces dernières. Dans un premier temps, les chercheurs ont recueilli des données sur les conditions de navigation dans les glaces, à l'occasion de trois périples à bord de l'Arctic, un minéralier de cote arctique, propriété de Canarctic Shipping Company Ltd. L'analyse de ces données a permis l'élaboration du programme des besoins des usagers et d'un cahier des charges fonctionnel du système envisagé. Le rapport décrit également les éléments matériels d'un prototype du système.

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SUMMARY

The overall objective of the MIDAS program was to develop an integrated facility that is capable of providing both strategic and tactical level information on ice conditions for ships and offshore drilling vessels operating in the Arctic and other ice-infested waters.

The field of remote sensing has expanded rapidly in recent years such that it is now possible for marine operators to obtain reliable information on ice conditions and hazards from a variety of sensors and platforms. This information is utilized for route planning and navigation by ships in transit and for site monitoring and evaluation by fixed area operators. The main sources of this information include satellites (IR/visible), airborne radars (SLAR/SAR) and conventional marine radars. The successful demonstration of the utility of this remotely sensed data for ice navigation has greatly influenced the thinking on marine operations in the Arctic. It is now possible for smaller class icebreakers and tankers to extend their operations by making use of this new technology. This represents a departure from conventional thinking which is to build larger, heavier vessels and ice breakers.

While this information has greatly increased the safety and reliability of offshore operations, it has also created problems for those persons who were required to deal with the large amount and different nature of the data generated. MIDAS (Multi-Task Ice Data Analysis System) was proposed as a solution to these problems.

An early model for a MIDAS system was proposed by INTERA based on experience gained from several years of operation in the Canadian Arctic. MIDAS would be a system capable of receiving and utilizing all of the above mentioned information sources. It would be designed to work on the bridge of a ship or at a local ice information centre and provide an integrated approach to the display and analysis of this remotely sensed data.

The objective of the work conducted by INTERA and reported here was to start with this conceptual model of a baseline system and then to collect and study the data necessary to refine this concept. This was necessary since there existed no data upon which to base a system design. Specifically, this Transportation Development Centre (TDC) contract was aimed at developing a design for a shipboard version of the MIDAS system.

During the course of this project, three field operations were undertaken to provide the necessary information for a detailed MIDAS design. All of these operations were carried out on-board the Arctic class ore carrier the M.V. Arctic - a facility provided by Canarctic Shipping and judged to be ideal for this study. The analysis of these operations resulted in a detailed user requirements document and functional specification for MIDAS. These are the prime products of this report.

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1. INTRODUCTION

This document presents the functional specifications for MIDAS (Multi-Task Ice Data Analysis Facility) based on experience gained by INTERA while working with the major drilling operators in the Beaufort Sea over the last five years and on the results of three field trips to the Eastern Arctic carried out on behalf of Transportation Development Centre (TDC) by INTERA on board Canarctic's ship the M.V. Arctic. MIDAS is an integrated facility that utilizes remotely sensed data for close range hazard detection and for strategic and tactical ice navigation. This system makes it possible to selectively route a vessel through an ice field minimizing contact with the ice encountered and avoiding contact with heavy ice.

1.1 Background

The dominant factor in Canada's northern offshore environment is more or less the continuous presence of ice in various forms and concentrations. This fact has severely restricted marine transportation both locally among the scattered settlements and outports which make up the Arctic and along the corridors through the Bering Strait and Labrador Sea. Figure 1 shows the extents of the winter ice conditions in the Canadian Arctic. Figure 2 shows the extent of this coverage in the summer during a very good year when ice conditions are not heavy. With the growing commercial development of the northern offshore frontier areas and the growth of mining and other land based activities in the high Arctic there has arisen the need for better and more reliable information on ice conditions for improved marine transportation.

Those operators who require such ice information include: ice breakers and ice breaking tankers capable of year round operations, lightly ice reinforced vessels (Arctic class IV or less) not capable of unrestricted year round operations, and oil and gas industry related drilling and production platforms. Their operational areas are the Western Arctic including the Beaufort, Chukchi and Bering seas, the Central Arctic including the Arctic Islands and the Northwest Passage and the Eastern Arctic extending from Baffin Bay to Newfoundland.

During the fall of 1979, Dome Petroleum's subsidiary, Canadian Marine Drilling (Canmar), was able to extend its drilling season in the Beaufort Sea by making use of Synthetic Aperture Radar (SAR) imagery [1]. The near real-time imagery was made available to an ice strengthened drillship via a VHF data link and provided "snap-shot-like" view of the ice conditions in the vicinity of the operations. This was then used for icebreaker support and subsequent navigation back to the harbour.

Since that time, the use of remotely sensed data such as SAR and SLAR has expanded rapidly so that it is now possible for marine

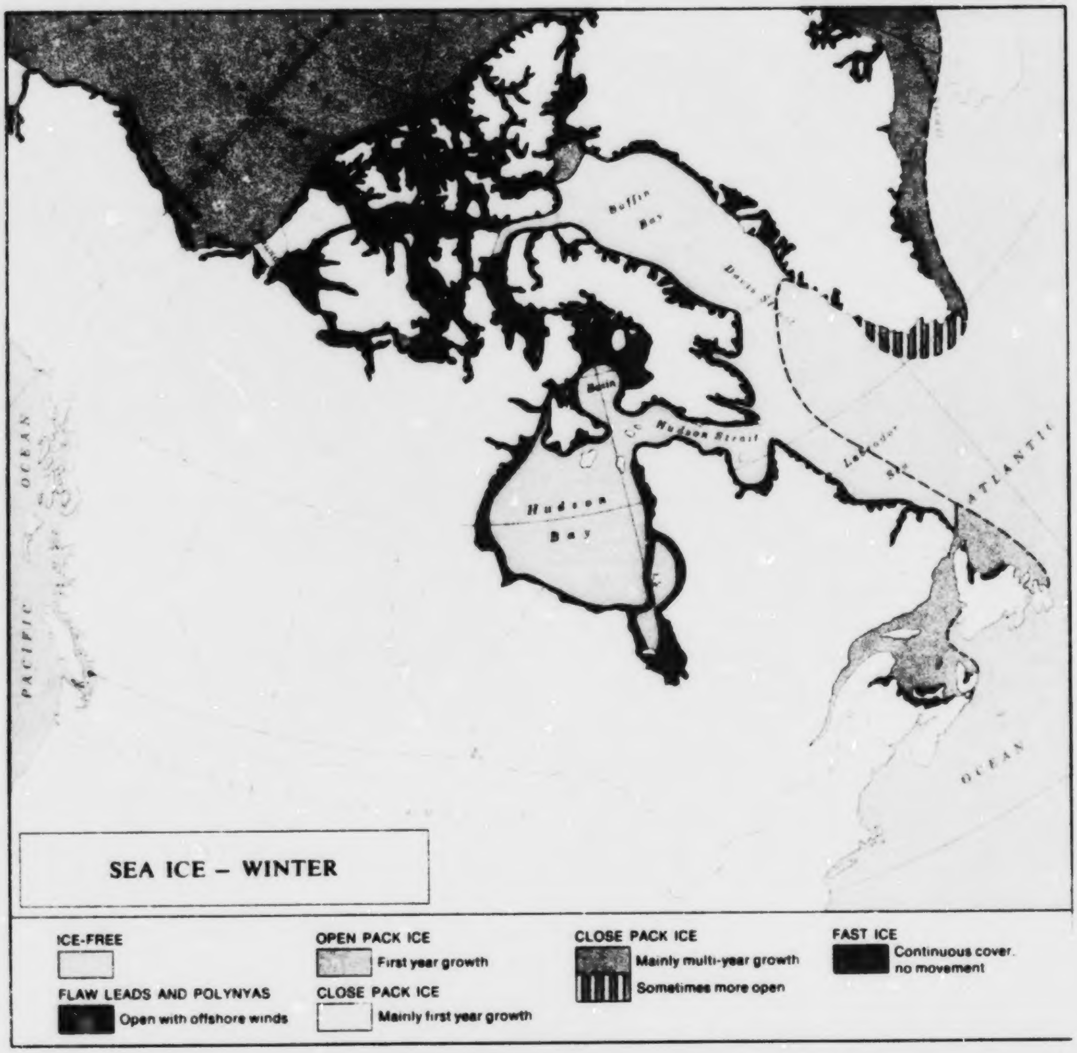
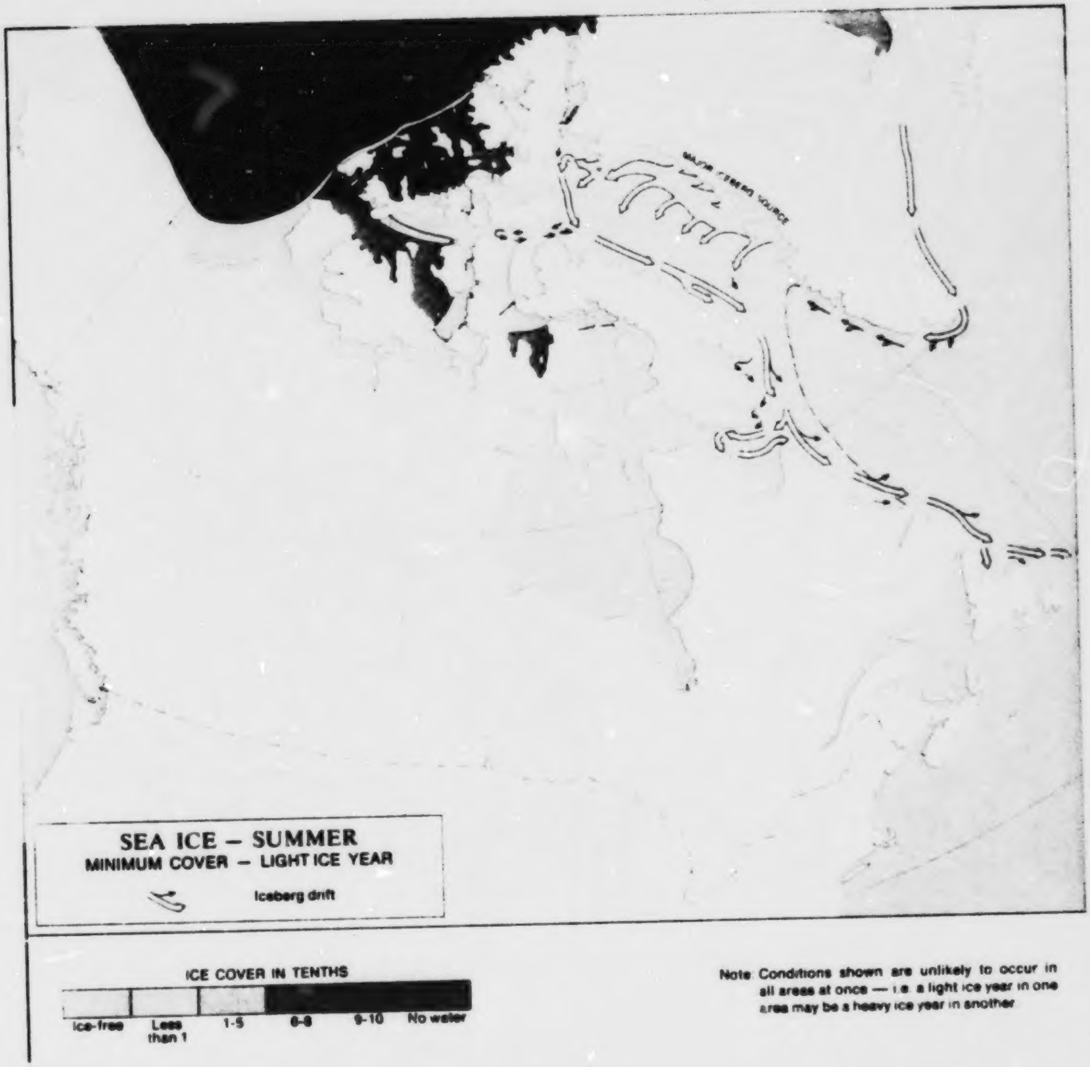

Baffin Bay
Davis Strait
Basin
Hudson Strait
Hudson Bay
Labrador Sea
ATLANTIC
OCEAN
PACIFIC OCEAN
SEA ICE – WINTER
ICE-FREE
FLAW LEADS AND POLYNYAS
Open with offshore winds
OPEN PACK ICE
First year growth
CLOSE PACK ICE
Mainly first year growth
CLOSE PACK ICE
Mainly multi-year growth
Sometimes more open
FAST ICE
Continuous cover, no movement

Figure 1. This map shows the extent of the winter ice conditions in the Canadian Arctic.


SEA ICE – SUMMER
MINIMUM COVER – LIGHT ICE YEAR
Iceberg drift
MAJOR ICEBERG SOURCE
ICE COVER IN TENTHS
Ice-free
Less than 1
1-5
6-8
9-10
No water

Note Conditions shown are unlikely to occur in all areas at once — i.e. a light ice year in one area may be a heavy ice year in another

Figure 2. This map shows the extent of the summer ice condition in the Canadian Arctic for a light ice year.

operators to obtain reliable all weather information on ice conditions and hazards. In face, a comprehensive study called "REMSCAN" (Remote Sensing Communications and Navigation) was undertaken by Transportation Development Centre, Transport Canada (TDC) to develop a coordinated approach to the acquisition, processing, and dissemination of the information necessary for safe, efficient marine transportation and other offshore activities in the arctic environment [2].

The Canarctic Shipping Company, Limited has also undertaken an extensive research program to develop new techniques for navigating in ice [3]. Canarctic owns and operates the M.V. Arctic, a Canadian built Class 2 icebreaking bulk carrier. Since 1978, the ship has carried lead/zinc concentrates to Europe from the Nanisivik mine on Baffin Island; Canarctic began the same service from the Polaris mine on Little Cornwallis Island in 1982.

Both Canarctic and INTERA have been working together over the last two years to develop an integrated ice information system to be used on commercial icebreaking ships. Canarctic has pioneered work on ice hazard detection systems and ice navigation techniques using remotely sensed data under a program titled "SINSS" (Shipboard Ice Navigation Support System). INTERA has been developing an integrated shipborne system called MIDAS (Figure 3).

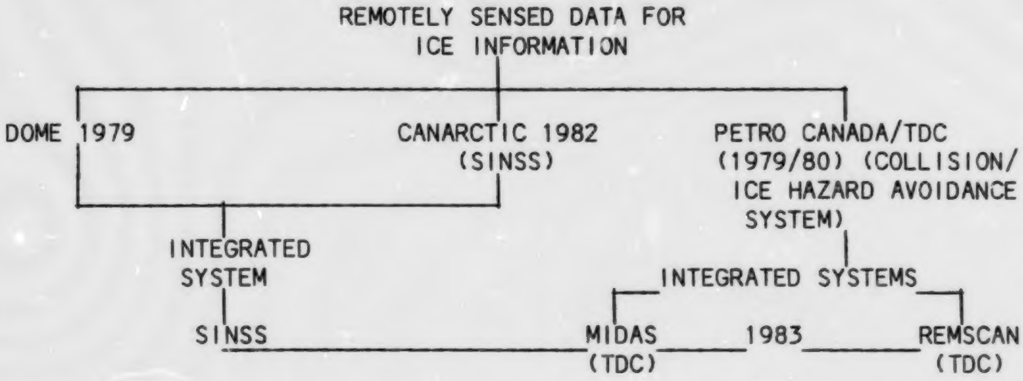

REMOTELY SENSED DATA FOR ICE INFORMATION
DOME 1979
CANARCTIC 1982 (SINSS)
PETRO CANADA/TDC (1979/80) (COLLISION/ ICE HAZARD AVOIDANCE SYSTEM)
INTEGRATED SYSTEM
INTEGRATED SYSTEMS
SINSS
MIDAS (TDC)
1983
REMSCAN (TDC)

Figure 3. A graphical illustration of how the MIDAS program evolved.

The information required by marine operators is generally organized into several categories which depend, to some extent, on how this information is to be utilized. For simplification these can be divided into: (1) strategic or long range forecasts of ice, weather and sea conditions; and (2) tactical, which describes the actual ice conditions in the immediate vicinity of the vessel. This includes close range hazards such as icebergs and growlers as well.

Strategic information is used mainly for operational planning and is required at headquarters and main operational bases. It must also be available to the masters of vessels and is used as the basis for route planning.

Tactical information must be continuously available to the ship's officers and offshore site managers. It is used for example to provide steering information for a ship traversing a field of ice or to warn a drilling rig of an approaching iceberg.

For strategic level planning interpreted ice charts which can be supplemented by real-time satellite imagery provide the first level of support. These may be supplemented by airborne radar (SAR/SLAR) if, for example, these products are not available or when more detailed information on ice conditions is desired.

For tactical support, what is required is an accurate map of the ice conditions to be encountered. It must be presented in sufficient detail to steer a ship or move a drilling rig off site if conditions warrant. That is, individual ridges or rubble areas, old ice or small icebergs in first-year ice should be detectable. Both Synthetic Aperture Radar (SAR) and Side Looking Airborne Radar (SLAR) are utilized for this task.

The need for a high resolution, wide swath, economical airborne radar system designed to support Arctic marine operations was recognized a number of years ago by INTERA. As a result, the STAR-1 System (Sea-Ice and Terrain Assessment Radar) was developed. This system is a digital real-time high resolution wide swath Synthetic Aperture Radar (SAR). It has proven to be an invaluable tool for the drilling operators in the Canadian Beaufort with all of the major oil companies suscribing to the flight service provided by INTERA. This service has been extended recently into the American Beaufort for drilling rigs and seismic ships. STAR-1 has also supported the M.V. Arctic on its voyages to the Eastern Arctic and resulted in substantial savings both in terms of travel time and fuel costs for the vessel. In fact, STAR-1 proved to be so beneficial that digital SAR imagery has become a required part of Canarctic's operation. Figure 4 shows STAR-1 imagery of Coburg Island in the Canadian Arctic taken during the spring of 1984. This area was used for a series of ramming tests carried out by M.V. Arctic on behalf of the Canadian Coast Guard. Figure 5 shows a photograph taken from the STAR-1 aircraft at the same time that the SAR imagery was collected. Notice that the cloud cover present in the photograph does not in any way show up on the radar imagery.

Table 1 lists a number of the sources of ice information which can be utilized for navigational purposes. Notice that several of these sources fit into more than one category.

Airborne SAR, for example, can be used for strategic planning by mapping large areas on the order of hundreds of kilometers. If the resolution is high enough, this same information can be used for close range hazard avoidance. INTERA's STAR-1 SAR typically images a ground swath 50 km in width and the endurance of the aircraft is such that large areas, such as Baffin Bay or Lancaster Sound, can be mapped during a single mission. This information can then be downlinked to a ship in near real-time. For a 50 km swath width, the resolution of the ground pixels is 12 metres by 12 metres which is suitable for close range hazard avoidance.

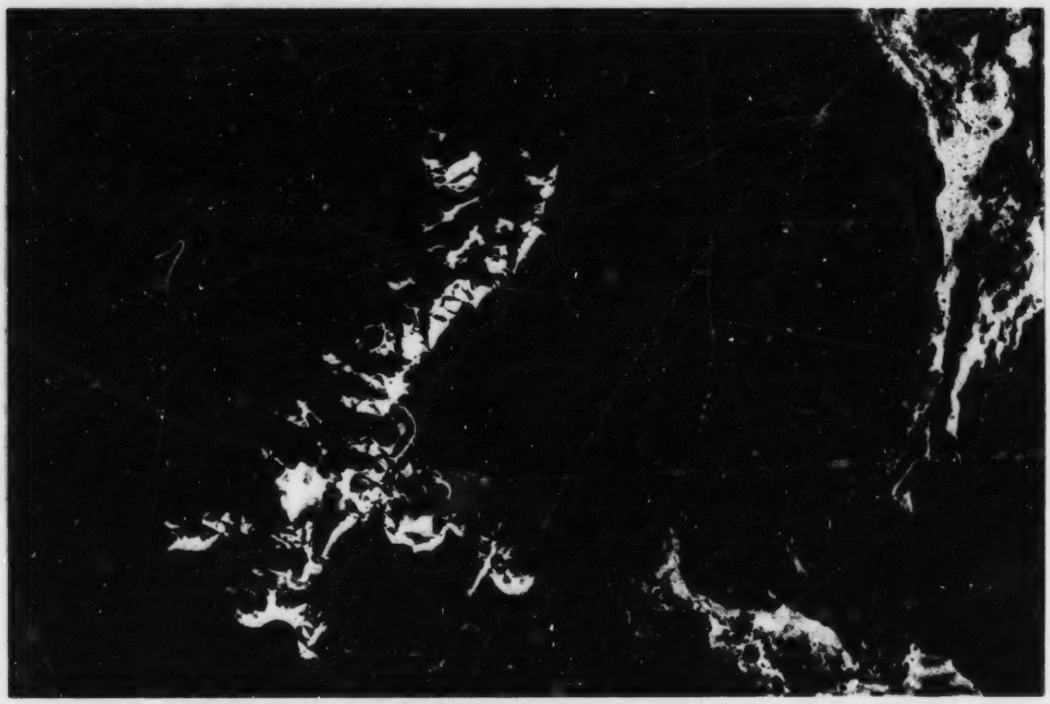


Figure 4 STAR-1 SAR imagery of Coburg Island in the Canadian Arctic taken during the spring of 1984. The landfast ice surrounding this island was used for a series of ramming tests conducted by the Canadian Coast Guard. First year ice, old ice and rubble areas can easily be distinguished on the SAR image.

Figure 5 Visual imagery of Coburg Island in the Canadian Arctic taken from the STAR-1 aircraft at the same time the above SAR image was recorded. Note that the cloud cover obscures the image so it is difficult to classify the ice

STRATEGIC (100 - 1000 km)	TACTICAL (25 - 200 km)	CLOSE RANGE (0.5 - 50 km)
- interpreted ice charts	- SLAR (airborne)	Marine Radar
- Weather forecasts	- SAR (airborne)	Sonar
- Satellite;	- Marine Radar	Coadar (H.F.)
NOAA		
LANDSAT		
METEOR		
- Passive Microwave		
- SLAR airborne and		
- SAR spaceborne		

Table 1 Sources of ice information for ice navigation.

1.2 MIDAS Operational Scenario

There were two operational scenarios proposed for MIDAS. The first involves a system that can be located at a ground based or offshore command centre, that is capable of receiving downlinked SAR and SLAR imagery and other environmental data products, that is capable of processing them in near real-time and producing image mosaics, ice data charts, and motion data for ice dynamics models. Under some conditions this system will be required to supply data either in raw form or in segmented or analyzed form to other users. This type of system is required by drilling operators such as Dome and Gulf Oil Canada Ltd. who operate in the Beaufort Sea [1]. The REMSCAN Study sponsored by TDC attempted to address the needs of this community of users. Figure 6 shows an artist's sketch of how the redistribution of airborne radar data could take place from a stationary drillship to ice breaking support vessels.

The second operational scenario for MIDAS requires that a system be located on the bridge of a ship and provide strategic and tactical level information to navigate in ice infested waters. The requirement here is that the system must be able to receive downlinked SAR and SLAR imagery from the aircraft and display that imagery in a convenient format. It must also be able to process data from the ship's radar, navigation system, and from satellites, and future data sources. Figure 7 is an artist's sketch of how airborne radar imagery is transmitted to the bridge of a ship and used for tactical navigation.

Both the above operational scenarios involve a requirement to process, display and manipulate large volumes of imagery from SAR and SLAR sources, from marine radars and from satellites. Both systems must handle the data in near real-time, be robust, and be fully operational if they are to fulfill the needs in the field. MIDAS is intended to provide a flexible set of hardware and software to meet the requirements of these operations.

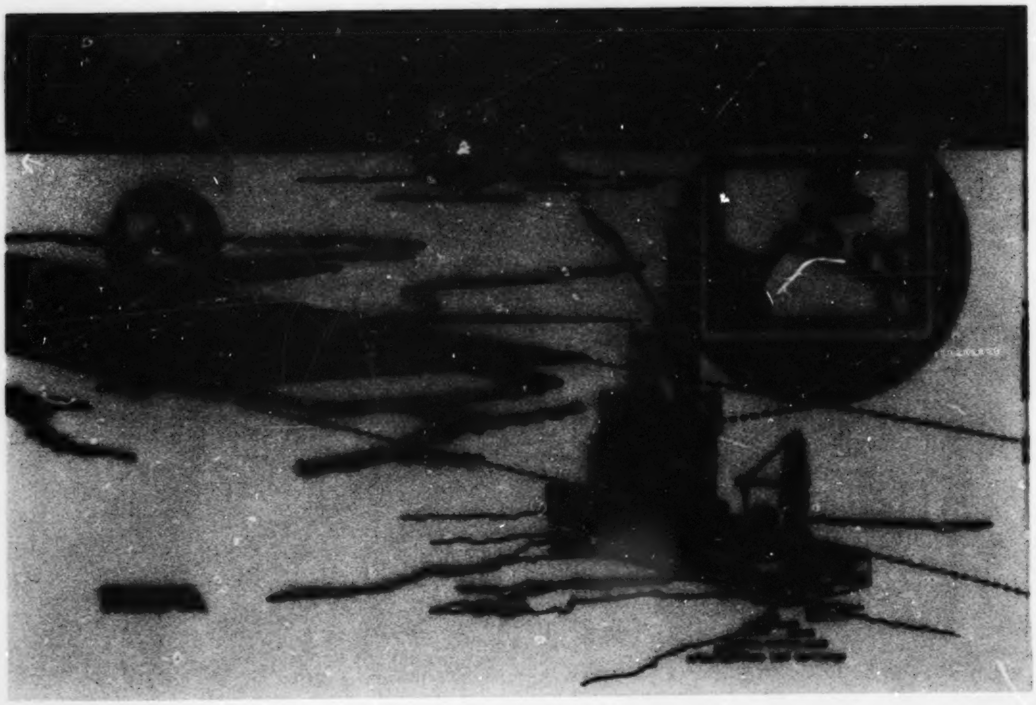


Figure 6 This is an artist's sketch of how the redistribution of airborne radar data could take place from a stationary drillship to ice breaking support vessels.

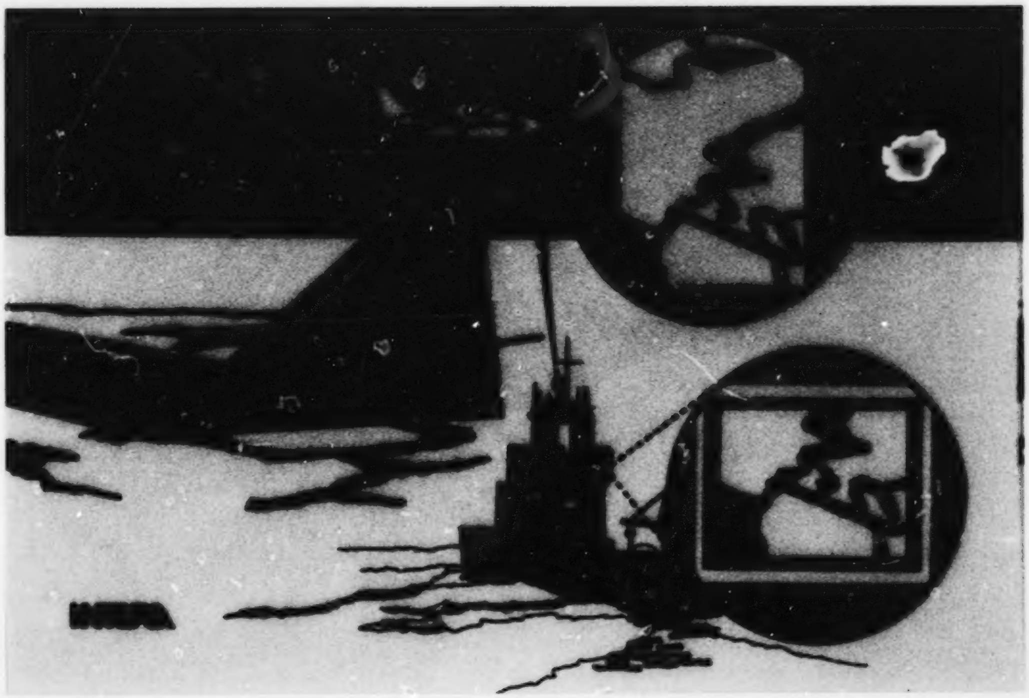


Figure 7 This is an artist's sketch of how airborne radar imagery is downlinked to the bridge of a ship and used for navigation.

Transportation Development Centre Canada recognized the need for a MIDAS type system to support marine transportation in ice. Ships navigating in ice are generally not threatened by the ice they encounter, but rather are impeded in their progress. The purpose of MIDAS is therefore to make the ship's progress much quicker and less costly in terms of fuel consumed, while lowering the risk of serious accident. The design of this ship-based MIDAS is the subject of this report. The ship-based system is emphasized since it was felt that such a system would provide the foundation upon which other more complex systems could be built.

The experience gained by INTERA, Canarctic, Dome and other organizations engaged in Arctic sea operations over the last few years has shown that airborne radar imagery downlinked in real-time to the bridge of a ship provides a very powerful strategic and tactical navigational tool. By staging periodic airborne radar missions, detailed ice information suitable for making both strategic and close tactical decisions can be made available to the vessel. The resulting savings in ship operating costs, reduction in vessel damage, and improvement in delivery schedules have proven to be very substantial.

Canarctic, operators of the M.V. Arctic were ideally placed to contribute to the development of the MIDAS system. Several years experience in the high arctic have also convinced Canarctic of the need for such a system. Their experience of the past three years has shown that their shipping season could be easily extended if marine radar, airborne radar, and satellite data were available in an easy to use form on the bridge of the ship.

In summary there are essentially two tasks to be accomplished by MIDAS. First, a ship must be able to select the optimum route through an ice field which normally means to minimize the ice encountered both in terms of quantity and severity along the route. Secondly, once a route is chosen, MIDAS must show the precise location of all close range hazards on that route.

1.3 Purpose of the MIDAS Study

The MIDAS project which was funded by the Transportation Development Centre was designed to accomplish the following objectives:

i. To identify the optimum remotely sensed image products that will aid both marine tranportation and offshore exploration in ice- infested waters.
ii. To demonstrate the usefullness of high resolution radar imagery for these applications;
iii. To collect a data set of airborne SAR imagery and marine radar imagery which is suitable for research aimed at developing an integrated analysis system;
iv. To perform a detailed task analysis to determine the user requirements for a MIDAS system;
v. To examine the market potential for MIDAS; and
vi. To provide a conceptual system specification for MIDAS.

2. STUDY APPROACH

Although the benefits of a MIDAS system were recognized by TDC no firm data existed upon which to base a design. Furthermore, the concept of using airborne radar imagery that can be downlinked in real-time and used along with the ship's own marine radar for close tactical navigation in ice had not been demonstrated. The requirements for the airborne radar, the marine radar and the other system's components which would make up MIDAS also had to be specified.

In order to test out the MIDAS concept INTERA organized a series of field operations using the M.V. Arctic as a research platform (Figure 8). These operations took place during the fall 1983, spring 1984 and fall 1984 voyages of the ship into Lancaster Sound in the Canadian Arctic. The voyage details are summarized in the following sections.

The field operations required that equipment be installed on board the vessel and that INTERA personnel travel with the ship. This development effort closely paralleled Canarctic's own development of (SINSS).

2.1 Strategic Information

The main sources of strategic information for route planning have traditionally been the ice and weather charts provided by the Atmospheric Environment Service (AES) which are supplemented by satellite photographs when available. Ice and weather charts are received on both digital and radio facsimile devices. The M.V. Arctic was equipped with a facsimile receiver and for the spring 1984 voyage a real-time satellite receiver system developed by Muirhead Systems Ltd., which receives IR and visual imagery from the NOAA 7 and 8 satellites. The study of the of these systems was an important part of the field operations since it was necessary to determine their utility for MIDAS.

To evaluate the use of airborne radar data for strategic purposes a receiver which is capable of receiving both INTERA SAR and SLAR and AES SLAR was installed on the ship. Once received by the ship, the radar data were printed on a high quality output device -a high resolution Fiber Optic Plotter which creates an image on photographic film. In addition to the hardcopy product, two tape drives were installed on the ship. Marine and airborne radar data were recorded on tape and used for future play-back and analysis.

2.2 Tactical Information

The tactical use of airborne radar for a navigating ship was also demonstrated in the field. The operational requirements for this kind of support were also determined. These proved to be

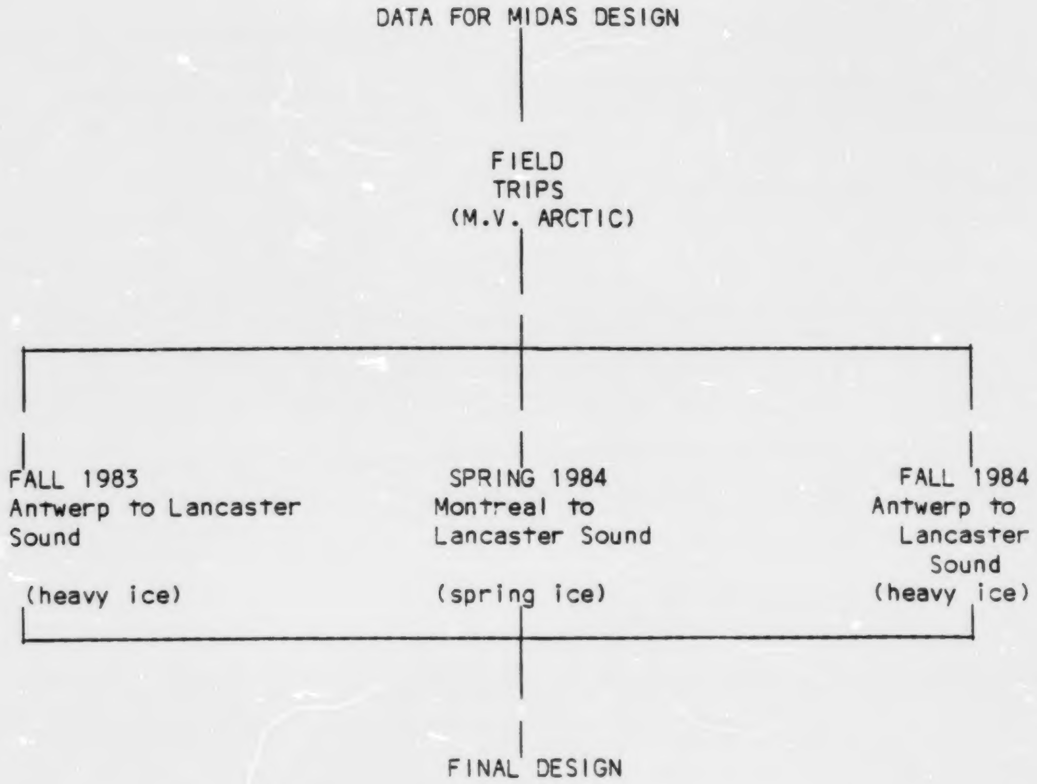

DATA FOR MIDAS DESIGN
FIELD TRIPS (M.V. ARCTIC)
FALL 1983 Antwerp to Lancaster Sound (heavy ice)
SPRING 1984 Montreal to Lancaster Sound (spring ice)
FALL 1984 Antwerp to Lancaster Sound (heavy ice)
FINAL DESIGN

Figure 8. In order to provide the details required for a MIDAS design a series of field trips were organized to the Canadian Arctic using the M.V. Arctic as a research platform.

substantially different from those of a stationary drilling rig in terms of area covered and resolution required. The information collected in the air and on the ground is relevant to marine transportation in a variety of ice types including young ice, first year ice, old ice, ice island fragments, growlers and icebergs.

The requirements of the marine radar display for a ship navigating in ice significantly differ from those of a ship operating in open water. For the most part, marine radars have been designed to provide the optimum target (i.e., ships and buoys) detection in the presence of sea clutter; there has been little or no effort to design radars for imaging large complex ice fields. The clutter from sea ice is generally more of a problem that the clutter from sea, both in theory and in practice. One of the prime goals of the MIDAS project then was to determine the requirements for an ice navigation radar.

To provide these requirements, the radar on board the M.V. Arctic was used along with INTERA's Radar Image Display System (RIDS). RIDS is a flexible digital system which processes, displays and records data from marine radars. It has been used for studies of sea-ice, icebergs, and other oceanographic applications. Data were recorded on standard computer compatible tapes (CCT). Table 2 summarizes the data sources that were available and analyzed during the field operations.

ICE INFORMATION SOURCE	FALL 1983	SPRING 1984	FALL 1984
ICE AND WEATHER CHARTS (FACSIMILIE)	X	X	X
AES SLAR	X	X	X
INTERA SLAR	X	-	X
INTERA SAR	-	X	X
MARINE RADAR (RIDS)	X	X	X
SATELLITE IR/VISUAL (REAL-TIME)	-	X	X

Table 2 shows the data sources that were used for the series of field operations that took place on the M.V. Arctic during the voyages to Lancaster Sound in the Canadian Arctic. (X indicates that these sources were available)

2.3 Data

The field operations yielded much of the data required for MIDAS design as well as providing the user requirements for such a system. The data collected during the field operations were later used in the laboratory for simulation and analysis. These data consisted primarily of:

i. SAR and SLAR data recorded under a variety of different ice conditions. These data were required to determine the quality, information content, resolution, etc., necessary for hazard recognition and ice classification. In addition, these data were required to determine the display requirements for MIDAS. The SAR and SLAR data were recorded on both CCT and HDDT tapes.

ii. Marine radar data recorded in a variety of different ice conditions. These data were recorded with the INTERA RIDS system on to CCT tapes. These data were used to determine the level of signal processing required, and other characteristics of an ice navigation radar.

iii. STAR-1 SAR and marine data recorded in the same operational area at the same time. These data were used to study the image-to-image correlations necessary to use these different data types for ice navigation.

The recommendations made in this report are based on the experience gained from these three field operations, the analysis of the data collected, interviews with prospective clients, and a detailed task analysis.

The MIDAS design effort was complicated by the fact that as new technology was made available to the ship's personnel it often became a requirement for their operation and hence MIDAS. Because of this fact, the traditional top down design methodology was difficult to apply. From the field activities however, an understanding of the requirements for a shipborne data analysis facility (MIDAS) emerged.

3. FIELD OPERATIONS

3.1 Fall Voyage (1983)

The first field trial, designed to collect data and test out the MIDAS concept, was organized for the M.V. Arctic's last trip of the season into Lancaster Sound in the fall of 1983. A SLAR/SAR downlink receiver, which is capable of receiving VHF transmissions from aircraft, and a bright TV marine radar display (RIDS) were installed on the ship in Antwerp in October 1983. The RIDS system uses a small computer to process data from conventional marine radars and displays it on a high quality colour video monitor. One key feature of this system is that the display can be maintained indefinitely which makes it useful for observing patterns in ice. Furthermore, marine radar data can be archived to both magnetic disk and computer compatible tapes (CCT's). Figure 9 is a diagram of the RIDS system. RIDS is more fully described in Section (4.2.3.3) of this report.

RIDS was connected to the ship's Sperry radars which unfortunately resulted in a rather marginal radar display. There was also no differential synchro available to the RIDS system consequently, the radar data displayed and collected had no north reference.

The airborne radar data used for this operation was primarily INTERA's SLAR since INTERA's STAR-1 SAR was still in the final development stage. AES's SLAR was received at one point in time, but these data were never used for the practical purpose of navigating the ship.

The SLAR data collected by INTERA's Conquest aircraft were transmitted to the downlink receiver on-board the ship and immediately printed on dry silver transparency. Thus, the airborne imagery was available to the navigating officers only minutes after it was collected. SLAR data were also recorded on CCT's.

3.1.1 Operation

As the ship approached the west coast of Greenland, ice charts supplied by AES ice patrol provided a strategic view of ice coverage. With this overview, the ship's operators were able to choose areas that would require SLAR coverage. The request for SLAR support was then transmitted to the flight crew 12 to 24 hours prior to the ship reaching these areas. Communication with the flight crew was direct via HF and VHF radio and indirectly via INMARSAT. INTERA's SLAR was operated in narrow swath, high resolution mode where heavy ice conditions were known to exist. Once the imagery was received it was annotated, and they passed to the ice interpreters on board the vessel and the best route through the ice was determined. Figure 10 is a photograph of the downlink receiver that was installed on the ship. The hardcopy image product (SLAR) that was available for analysis is also shown. As the ship progressed through the ice, its location on

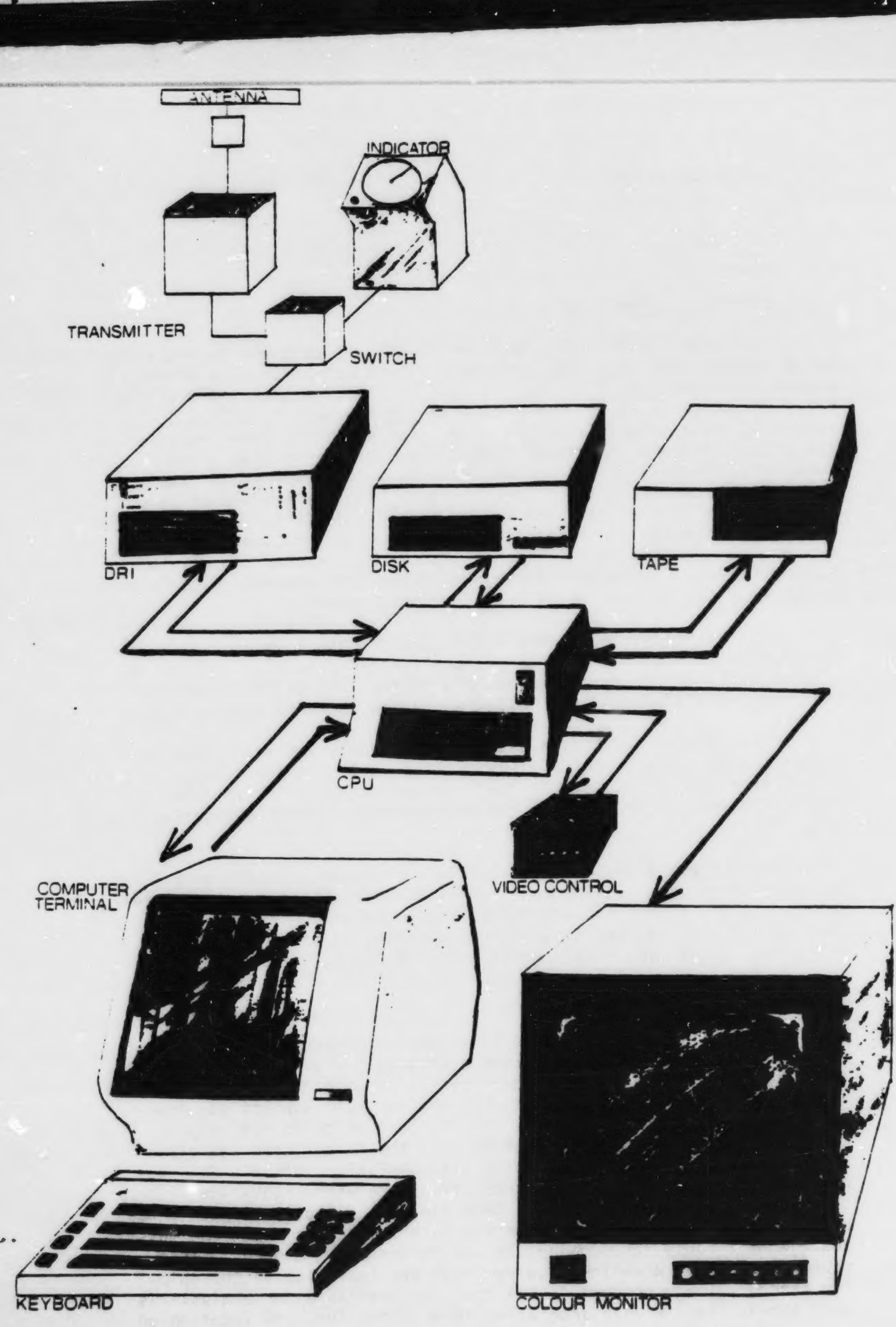

ANTENNA
INDICATOR
TRANSMITTER
SWITCH
DRI
DISK
TAPE
CPU
COMPUTER TERMINAL
VIDEO CONTROL
KEYBOARD
COLOUR MONITOR

Figure 9 Diagram of INTERA's RIDS system.

the imagery was plotted on the image strips to maintain a fix of the ship's position. This position was determined by matching images of ice floes from the marine radar (RIDS) display with the floe shapes on the SLAR imagery. Where there were few distinct features the ship's location was determined by plotting its latitude and longitude on the imagery or by matching shore features when close to land. Figure 11 is a photograph of the M.V. Arctic breaking ice in Lancaster Sound during this voyage.

3.1.2 Data

The data sets collected during this voyage contain SLAR data recorded on the aircraft, SLAR data received from the aircraft and recorded on board the ship, and marine radar data recorded by the RIDS system.

3.1.3 Results and Observations

The SLAR data available for this mission was of very marginal quality so the initial problem of identifying the ship's location on the SLAR imagery proved to be very difficult; however, it was sometimes possible to observe the signature of the ship and its track. Keeping track of the ship's position was also very complex and using the ship's marine radar was the only way of accomplishing this task. It was shown that a bright marine radar display that persists for long periods of time, like INTERA's RIDS, is necessary to maintain a fix of the ship's location on the airborne imagery. The ship's main marine radar system used for this study (Sperry), however, was only marginally acceptable for the task of generating a high quality image for RIDS. This is due to the fact that the Sperry radar uses a linear receiver hence suffers from saturation and the effects of unwanted clutter. This was unfortunate and the data collected by the RIDS system were of rather limited value for future analysis.

The wide area ice coverage shown on the ice charts supplied by AES provided the ship's navigating officers with a much needed overview for strategic planning. They were thus able to choose the heavy ice-covered areas that would require more detailed SLAR coverage for tactical navigation.

The AES SLAR was generally not useful for this voyage. This was because the transmission was received while the ship was in an area that did not require SLAR coverage and the flight path of the aircraft was such that the area imaged was a long way from the ship's proposed course. SLAR data have been available for some time to ship's equipped with the necessary receiver from government agencies like AES; however, these data are recorded in a very wide swath mode and coverage is limited to routes that are selected well in advance by a central agency. This limits the utility of these data for a navigating ship. The coverage may also not be wide enough to be useful for strategic planning and may not be of high enough resolution for tactical navigation.

Figure 10 This photograph shows the downlink receiver that was installed on the M.V. Arctic in the fall of 1983. The hardcopy SLAR image product that was available for analyses is also shown.

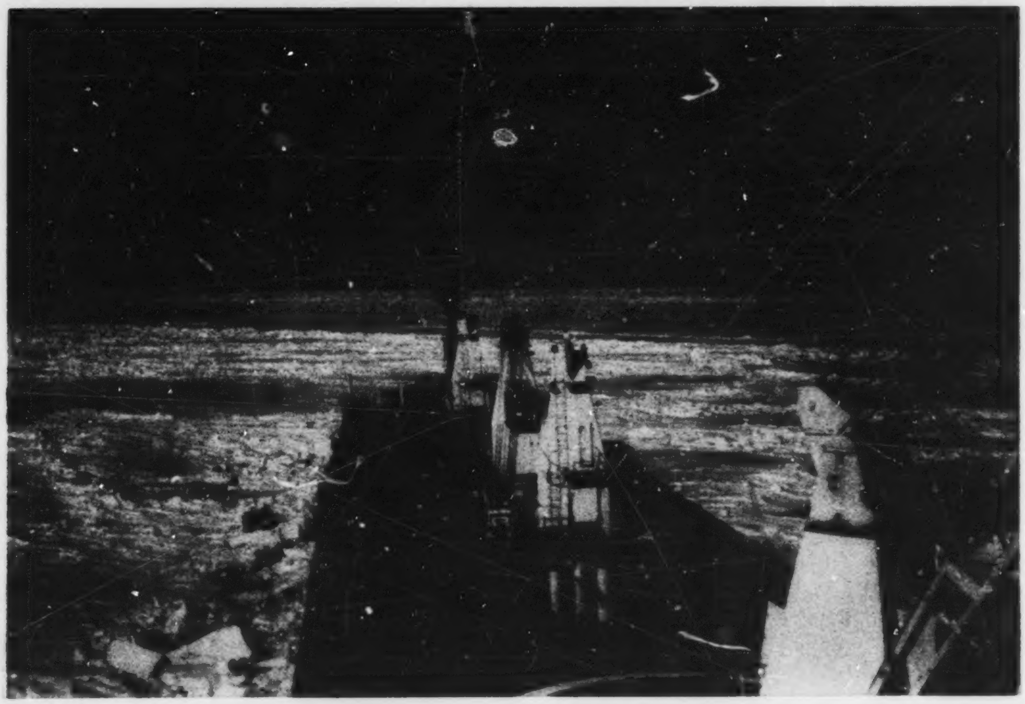


Figure 11 The M.V. Arctic breaking ice in Lancaster Sound during the fall of 1983.

This presents a problem for those operators who require detailed ice coverage for tactical navigation and rely solely on current government sources for this information.

INTERA's SLAR was able to provide strategic information for the ship. The downlink has a range of approximately 200 nautical miles, (line of sight), but this coverage was extended by the aircraft recording data onto HDDT tape and then loitering over the ship while downlinking this stored data. This SLAR was just marginally acceptable for tactical navigation in heavy ice though, even when it was operated in narrow swath, high resolution mode. The SLAR imagery also required that geographical annotation be passed over a VHF radio. Once the information was annotated, it was passed to the ice observers who placed it on a map-like grid so that steering information could be provided to the ship's Master. Observers often spent several hours analyzing the data to choose the best route.

During this trip much was learned about the logistics of operating a MIDAS system. Communications are a constant problem in the Arctic and HF and VHF radio are not always reliable. Airstrips are also limited so the length of time an aircraft can collect data in any given area is also restricted. The ship's progress through the ice was often not well known so it was necessary to change the flight plans many times. Depending on weather conditions and ice movements, the SLAR data was often only good for a few hours after it was collected.

The MV Arctic was equipped with an optical system designed to enlarge the SLAR transparencies that were produced by the fibre optics plotter (Figure 12). This system was used regularly to zoom in on selected areas on an image strip to provide more detail. Its success was restricted however, due to the limited resolution hard copy product available and the generally poor quality of the SLAR data. (The SLAR suffered from aircraft yaw, a motion problem common to this type of data). It was necessary to produce two copies of an image - one to be enlarged and the other an overview image. The enlarged section was used to steer the ship while the overview was used for more strategic decision making. Despite the rather poor quality of the SLAR image products and marine radar available, they were sufficient to aid navigation in the heavy ice encountered and therefore to validate the MIDAS concept. The voyage was viewed as a successful demonstration of the use of remotely sensed data to aid ships navigating in ice. These results are summarized in Table 3.

3.2 Spring Voyage (1984)

As a result of the success of the first field trial, a second field trip was organized by INTERA. This took place on the M.V. Arctic's first trip of the season in June of 1984. Both the SAR/SLAR downlink (which was purchased by Canarctic from INTERA) and the RIDS were again installed on the ship. Several areas of the operation, however, were improved over the previous year.

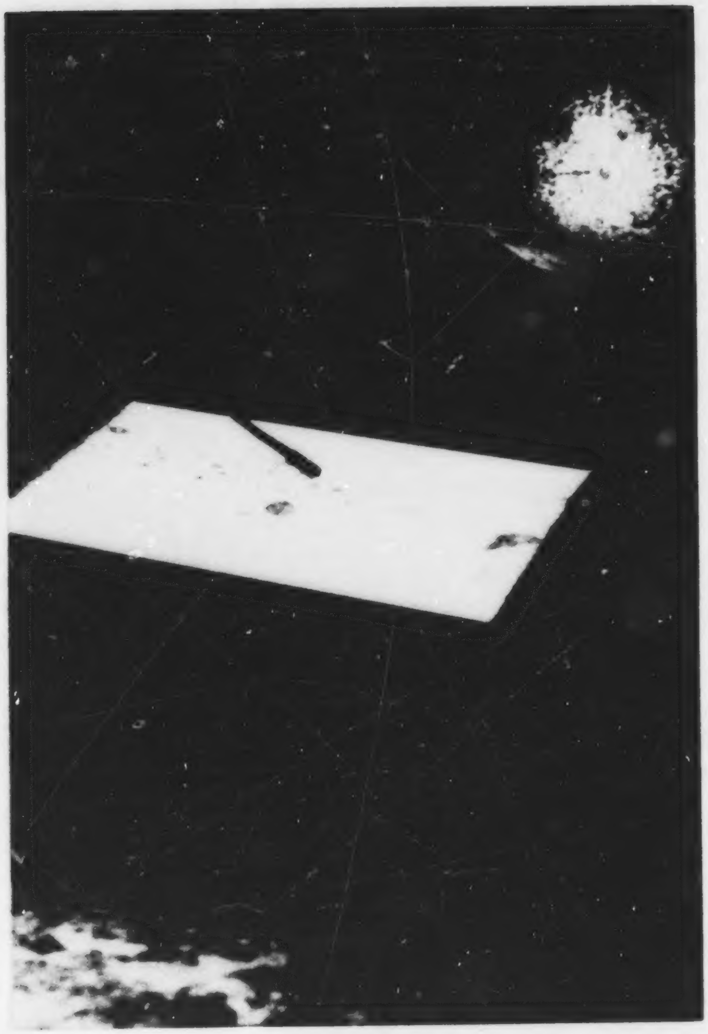


Figure 12 The system currently being used aboard the M.V. Arctic to track the position of the ship on the airborne radar transparencies using the marine radar display (upper right). One copy of the airborne radar imagery is placed on a light table (centre) and a second copy "enlarged" and used for tactical navigation. A portion of this expanded image is shown in the bottom left hand corner of the photograph.

ICE INFORMATION SOURCE	RESULTS
ICE AND WEATHER CHARTS	- RECEPTION PROBLEMS - TIMELINESS A PROBLEM - INTERPRETATION QUESTIONABLE
AES SLAR	- TIMELINESS A PROBLEM - POOR DATA QUALITY - NOT USEFUL FOR TACTICAL NAVIGATION
INTERA SLAR	- POOR DATA QUALITY "MARGINALLY" USEFUL FOR TACTICAL NAVIGATION BY SKILLED INTERPRETERS
MARINE RADAR RIDS	- POOR IMAGE DUE TO SPERRY RADAR, (LINEAR GAIN)

Table 3 Summary of the results of the fall 1983 voyage of the M.V. Arctic.

The airborne radar data used for this experiment was the INTERA STAR-1 SAR; a fully digital SAR that has excellent radiometric characteristics (Figure 13).

The technical problems that existed the previous year with the ship's radar were rectified with the installation of a new marine radar (DECCA). This radar employs a lograthmic receiver with a low noise amplifier. A permanent cabling arrangement was also installed providing stabilized synchro, unstabilized synchro and video signals to RIDS. Thus RIDS was capable of displaying and recording north-up as well as ship's head-up radar data. RIDS also operated independently of the ship's PPI display.

In addition, a speed control was installed that allowed the rotational speed of the antenna to be slowed making it possible to do more pulse to pulse averaging at the RIDS digital radar interface (DRI). Pulse to pulse averaging is a convenient way of suppressing noise and aiding target detectability.

A visual/IR satellite receiver (VIEWFAX) was also installed on the ship by Muirhead Systems Limited. This image display system was designed to provide real-time IR and visual satellite imagery from the NOAA 7 and 8 satellites.

3.2.1 Operation

To select the optimum routes through the ice on the way to Cobourg Island wide area strategic ice coverage was again provided by AES in the form of ice charts. This information was supplemented with satellite photographs that were available before the ship departed Montreal, and real-time satellite images received by the Muirhead system. This information showed open water areas, and areas where the ship would encounter ice and require SAR support. Marine radar data were collected under a variety of weather conditions while the ship was in open water and in ice. Figures 14 and 15 are photographs taken from the bridge of the ship of several of the icebergs encountered along the west coast of Greenland.

The request for SAR support was made via telex on INMARSAT to the STAR-1 flight crew in Inuvik approximately 24 hours in advance of the ship's estimated time of arrival in the heavy ice areas.

STAR-1 provided imagery for the ship once it reached a point about 100 miles north of Disko Island. These data were taken in wide swath mode (50 km) from an altitude of approximately 10,000 metres. VHF communication was established with the aircraft to coordinate the transfer of the SAR imagery. As the real-time SAR imagery was received, it was easy to recognize different ice types and the open water areas were clearly visible. As the ship progressed through the ice its location on the SAR imagery was plotted to maintain a fix of the ship's position and provide steering information to the ship's Master. The RIDS display provided the means of identifying the ship's position on the imagery since the shapes of ice floes matched those on the SAR.

Figure 13 INTERA's Cessna Conquest twin turboprop aircraft. These aircraft have an operational ceiling of 10,000 m. above sea level and are used to carrying both SLAR and SAR radar payloads.

Figure 14 Iceberg encountered by the M.V. Arctic during the spring voyage of 1984 along the west coast of Greenland.

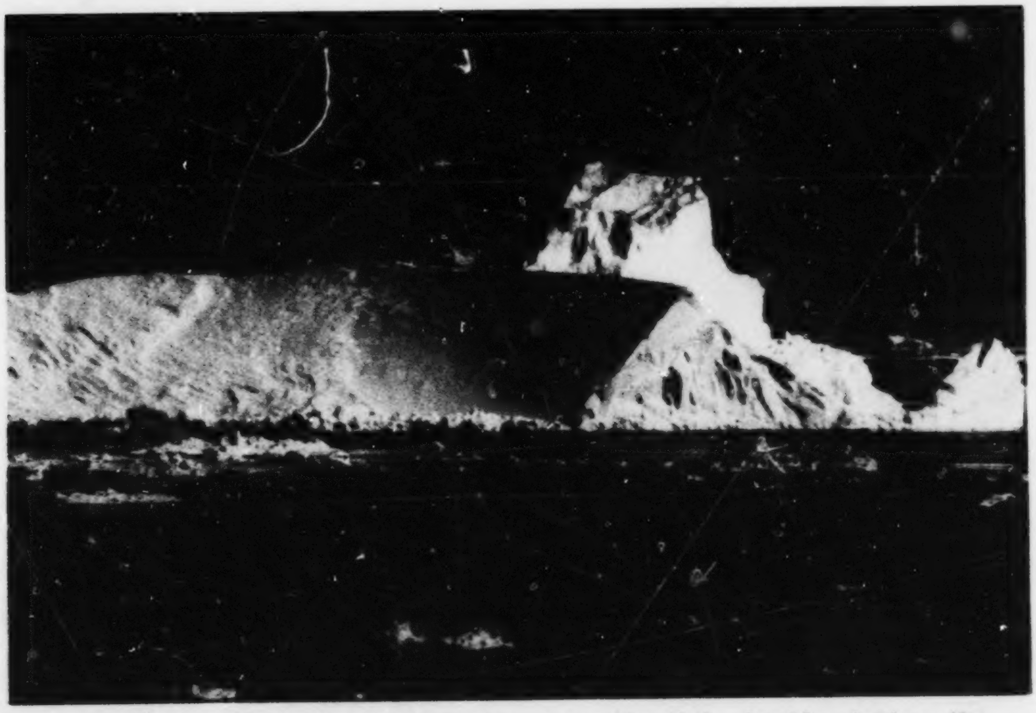


Figure 15 Iceberg encountered by the M.V. Arctic during the spring voyage of 1984 along the west coast of Greenland.

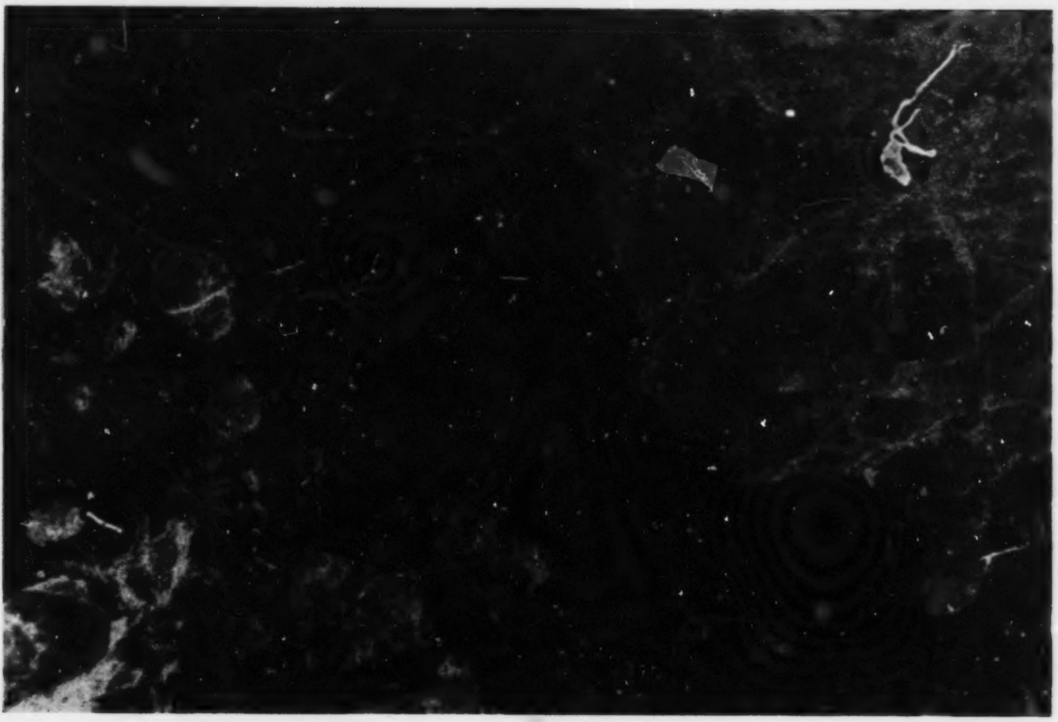


Figure 16 SAR data recorded during the spring voyage of the M.V. Arctic and downlinked to the ship in real-time from the aircraft.

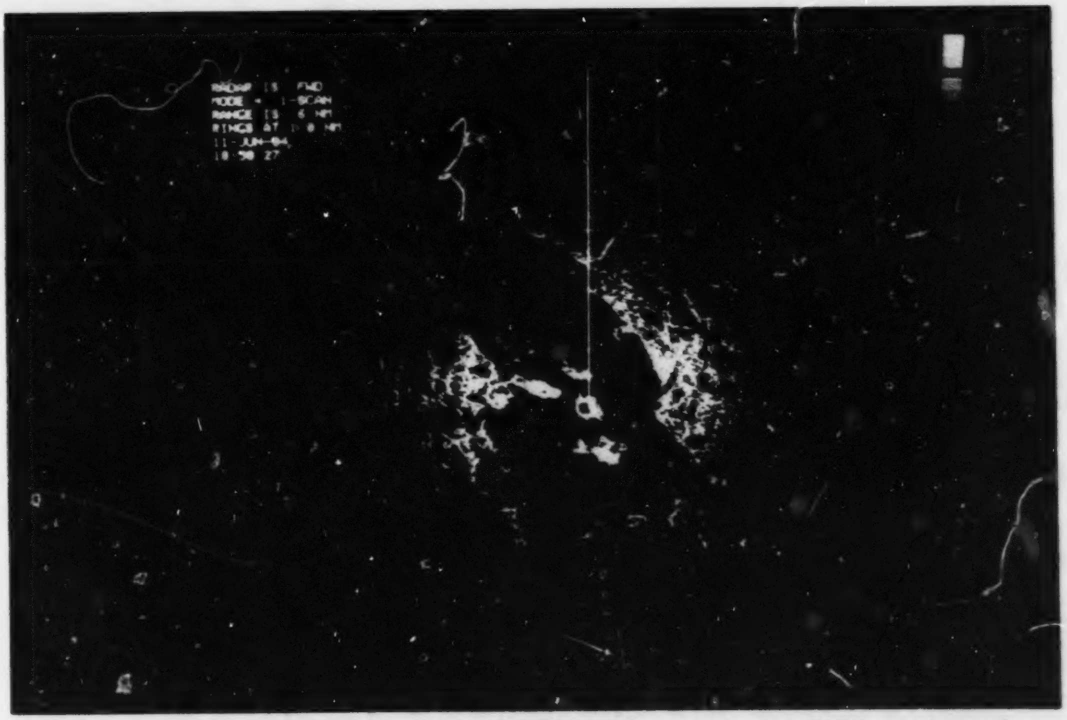

RADAR IS FWD
MODE = 1-SCAN
RANGE IS 6 NM
RINGS AT 1.0 NM
11-JUN-84
10 50 27

Figure 17 Marine radar data displayed on the RIDS system of the same operational area as that shown in the SAR image. Several floes are easily recognized even after several hours have past and the ice has moved.

Figures 16 and 17 show a marine radar image and a SAR image of the same area recorded during this voyage. Several of the floe shapes are easily recognized on both prints. Note that the ship arrived at this location several hours after the aircraft imagery were recorded and the ice has moved. It is still possible to use the SAR image for tactical navigation since the open water areas are clearly visible.

3.2.2 Data

The data sets collected contained SAR data recorded on the aircraft, SAR data received from the aircraft and recorded on board the ship, and marine radar data recorded from the ship's radars recorded by the RIDS system.

3.3.2 Results and Observations

The initial field trial on the M.V. Arctic in the fall of 1983 reaffirmed the concept of combining shipborne and airborne radar for navigation in ice. The image products available at that time, however, were rather limited in quality so no firm recommendations for a MIDAS system could be made. The technical problems associated with the 1983 experiment were rectified for the 1984 spring trial. By using SAR data and an improved marine radar display, the M.V. Arctic was able to avoid almost all the ice along its route.

The high quality SAR imagery available proved to be an excellent tool for tactical navigation. The 50 km swath of SAR imagery yielded 24 m x 24 m ground pixels and was sufficient for navigation in all of the ice encountered. The radiometrics were good enough that a high quality ice map was generated that could be interpreted by ship's personnel with little or no training in ice science. INTERA's SAR product, however, was not easy to use for navigating the ship since it is not georeferenced. The utility of this product would be greatly increased if latitude and longitude information were available directly on the imagery.

The marine radar display (RIDS) provided the means of identifying the ship's position on the airborne imagery. The higher resolution radar (DECCA) resulted in a much improved display. This radar uses a logrithmic receiver and a low noise amplifier to achieve a better signal to noise and better signal to clutter ratio than the older Sperry radar.

The visual/IR satellite receiver on-board the M.V. Arctic was not in operation long enough to evaluate all of its functiona, data management and enhancement tasks. The imagery received was limited however it was used when it was available. The results of this field trip are summarized in Table 4.

3.3 Fall Voyage (1984)

Having witnessed the success of the previous two field operations, Canarctic were fully committed to the MIDAS concept. At their expense, INTERA supported their final trip of the season into Lancaster Sound in October 1984. Canarctic recognized the need for a bright TV display for their marine radar, so INTERA's RIDS system was

ICE INFORMATION SOURCE	RESULTS
ICE AND WEATHER CHARTS	- TIMELINESS A PROBLEM - INTERPRETATION QUESTIONABLE
AES SLAR	- POORLY RECEIVED DUE TO HARDWARE PROBLEMS - TIMELINESS A PROBLEM
INTERA SLAR	- HIGH QUALITY DATA USEFUL FOR TACTICAL NAVIGATION WHEN USED WITH MARINE RADAR - CAN FORM BASIS OF ICE NAVIGATION CHART - CAN BE INTERPRETED BY SHIP'S MASTERS - LACKED ANNOTATION - DOWNLINK OPERATION COMPLICATED
MARINE RADAR RIDS	- BETTER IMAGE PRODUCT DUE TO IMPROVED RADAR (DECCA) - OPERATIONAL PROBLEMS WITH RADAR PROVIDED
SATELLITE (IR/VISUAL)	- PROVIDED SOME USEFUL INFORMATION - HARDWARE PROBLEMS PREVENTED FULL EVALUATION

Table 4 Summary of the results of the spring 1984 field trip on the M. V. Arctic.

again installed on the ship. Arrangements were made to have SAR and SLAR support to and from Little Cornwallis Island. The M.V. Arctic was also escorted by the Canadian Coast Guard ice breaker Sir John A. MacDonald during this operation.

3.3.1 Operation

AES ice charts were again used for strategic planning. These charts, however, were not always available nor accurate and the ship encountered ice on several occasions that was not anticipated. Unfortunately, Muirhead's VIEWFAX satellite receiver was not able to provide any strategic support so SLAR and SAR were used for both strategic and tactical purposes. SAR imagery; however, was required for close tactical support in heavy ice. RIDS was again used to track the vessel position on the imagery. Figure 18 shows the M.V. Arctic breaking ice in Lancaster Sound.

3.3.2 Data

Although the primary purpose of this particular field trip was to support Canarctic, the data sets collected contain SAR data recorded on the aircraft, SAR data received from the aircraft and recorded on board the ship, and marine radar data recorded from the ship's radars by the RIDS system. In addition, the users observations and comments on the use of the RIDS and the SAR/SLAR receiver were also recorded.

3.3.3 Results and Observations

The fall (1984) voyage of the M.V. Arctic yielded more information for the MIDAS design. Due to the problems of receiving AES ice and weather charts and the fact that when they were received they were not always accurate, it appears that real-time satellite receivers that receive broadcasts from polar orbiting satellites can be valuable for ships operating in the high Arctic or in other regions where communications are a problem.

INTERA's SAR and SLAR were both used for strategic and tactical ice navigation during this voyage. The SLAR was not very useful for tactical support when the ship was in heavy ice. It was also less than desirable at times for strategic support due to the poor resolution at the far range of the swath. The STAR-1 SAR, however, was used successfully for both tactical and strategic support. As a result of these operations Canarctic has concluded that when totally reliable ice information is needed, high resolution SAR is required. They have since modified their operational procedure to call for SAR support whenever their ship is in heavy ice. Figures 19, 20, 21 and 22 are marine radar and SAR image pairs taken of the same operational area during this voyage. Because of the heavy ice conditions it is extermely difficult to recognize patterns and hence determine the postion of the ship in the SAR images. These type of ice conditions represent the most difficult to be encountered and illustrate the need for high resolution airborne radar and marine radar data.

A survey of the users' comments regarding the operation and quality of the data products available also yielded much useful information for the MIDAS design. The results of the field trip are summarized in Table 5.

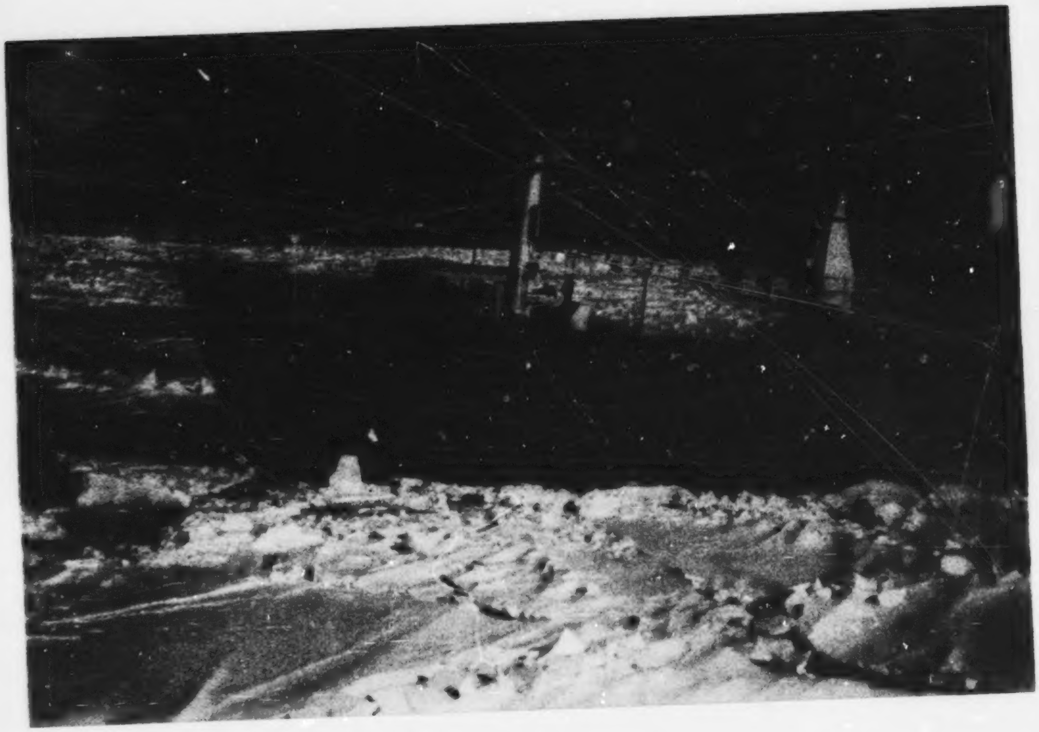


Figure 18 The M.V. Arctic breaking ice in Lancaster Sound.

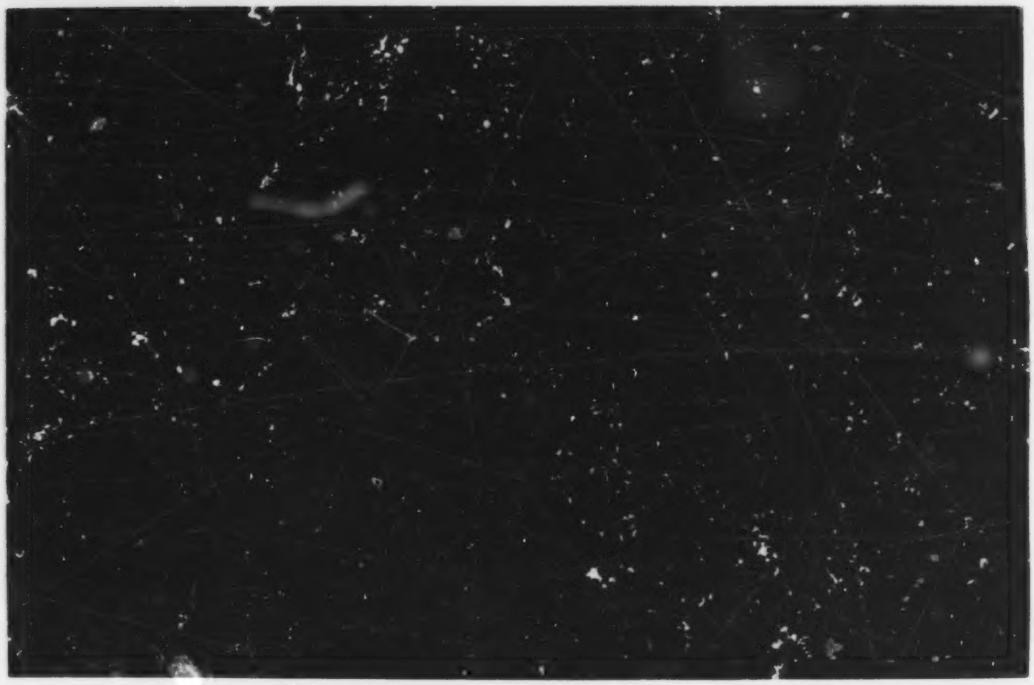


Figure 19 SAR data recorded during the fall 1984 voyage of the M.V. Arctic and downlinked to the ship in real-time from the aircraft.

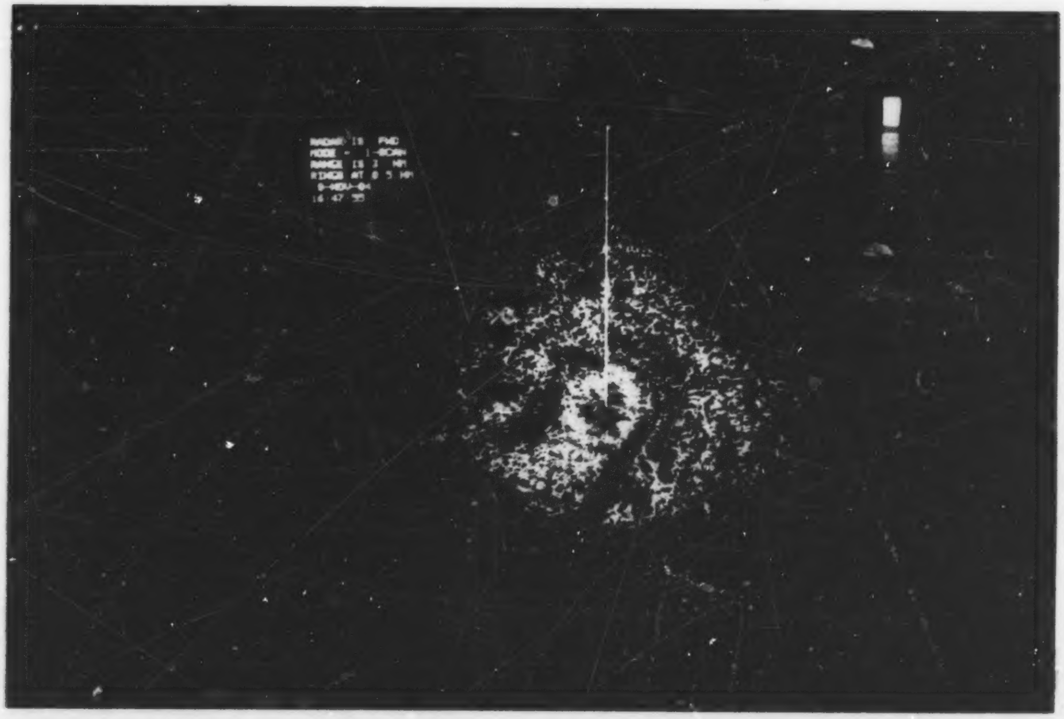

RADAR IS FWD
RANGE IS 3 NM
RIDGE AT 0.5 NM
16 47 35

Figure 20 Marine radar data displayed on the RIDS system of the same operational area as that shown in the SAR image. Because of the heavy ice conditions it is much more difficult to recognize the patterns and hence determine the position of the ship.

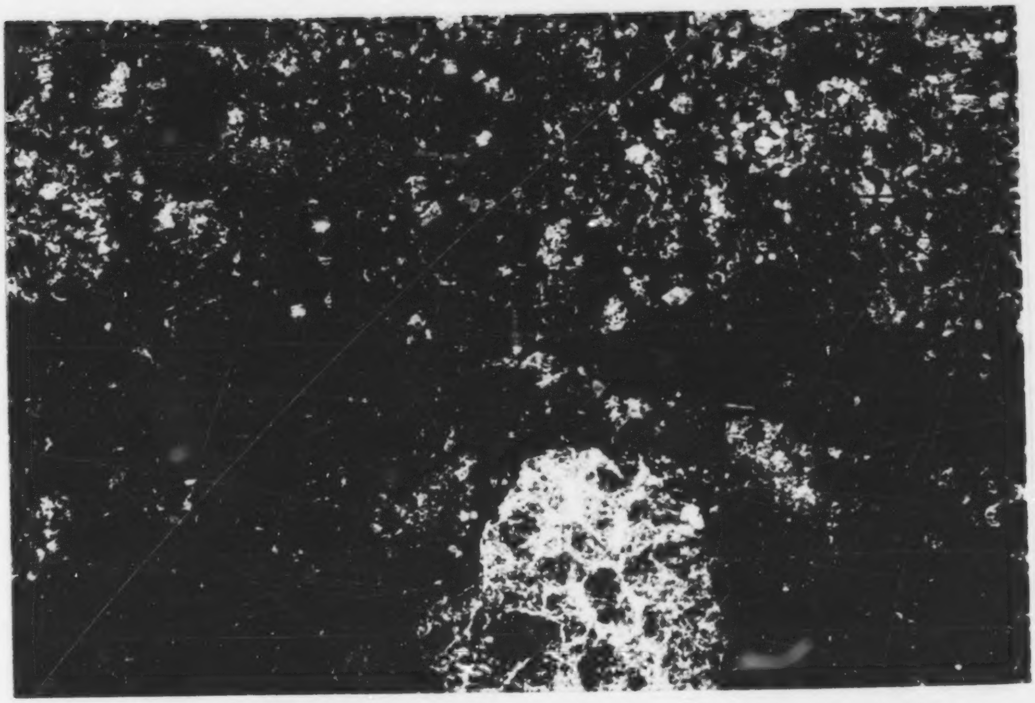


Figure 21 SAR data recorded during the fall voyage of the M.V. Arctic and downlinked to the ship in real-time from the aircraft.

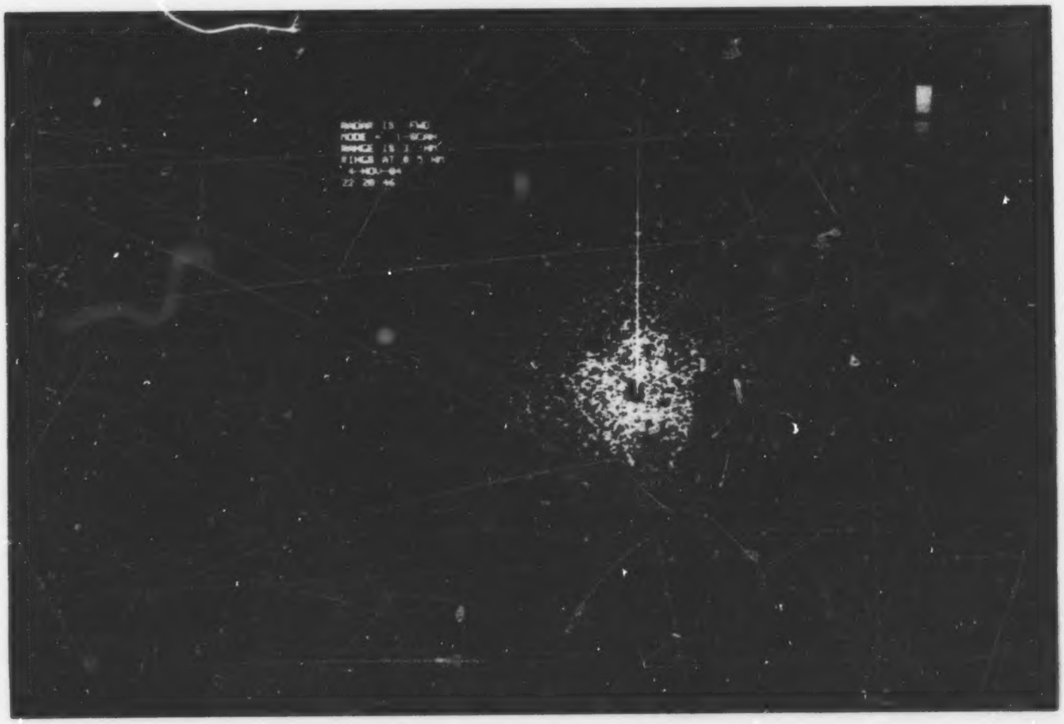


Figure 22 Marine radar data displayed on the RIDS system of the same operational area as that shown in the SAR image. Because of the heavy ice conditions it is much more difficult to recognize the patterns and hence determine the postion of the ship.

ICE INFORMATION SOURCE	RESULTS
ICE AND WEATHER CHARTS	- TIMELINESS A PROBLEM - INTERPRETATION A PROBLEM
AES SLAR	- TIMELINESS A PROBLEM - POOR IMAGE PRODUCT
INTERA SLAR	- POOR IMAGE PRODUCT FOR HEAVY ICE CONDITIONS - MARGINALLY ACCEPTABLE FOR STRATEGIC PURPOSES - UNACCEPTABLE FOR TACTICAL PURPOSES
INTERA SAR	- REQUIRED FOR TACTICAL NAVIGATION IN HEAVY ICE CONDITIONS
MARINE RADAR RIDS	- MARGINALLY ACCEPTABLE IMAGE PRODUCT DUE TO HEAVY ICE CLUTTER - DISPLAY TOO SLOW - RIDS TOO COMPLICATED
SATELLITE IR/VISUAL	- PROVIDED SOME USEFUL INFORMATION - HARDWARE PROBLEMS

Table 5 Summary of the results of the fall 1984 field trip on the M. V. Arctic.

4. MIDAS SYSTEM REQUIREMENTS

The MIDAS system requirements are based on the results of the field operations previously described and a detailed task analysis conducted by INTERA. MIDAS must be capable of supporting both fixed area marine operations as well as ships in transit in ice-infested waters. This requires that the system receive remotely sensed data, in near real-time, (with the time factor generally being more critical for the ship in transit). From this information provided, the ship must be able to select the optimum route through the ice which normally means to minimize the ice encountered both in quantity and severity. Once a route is chosen, MIDAS must show the location of all the exceptional close range hazards on that route. The information required for these operations has been categorized as either strategic or tactical. In the following paragraphs these information sources are discussed.

4.1 Strategic Information

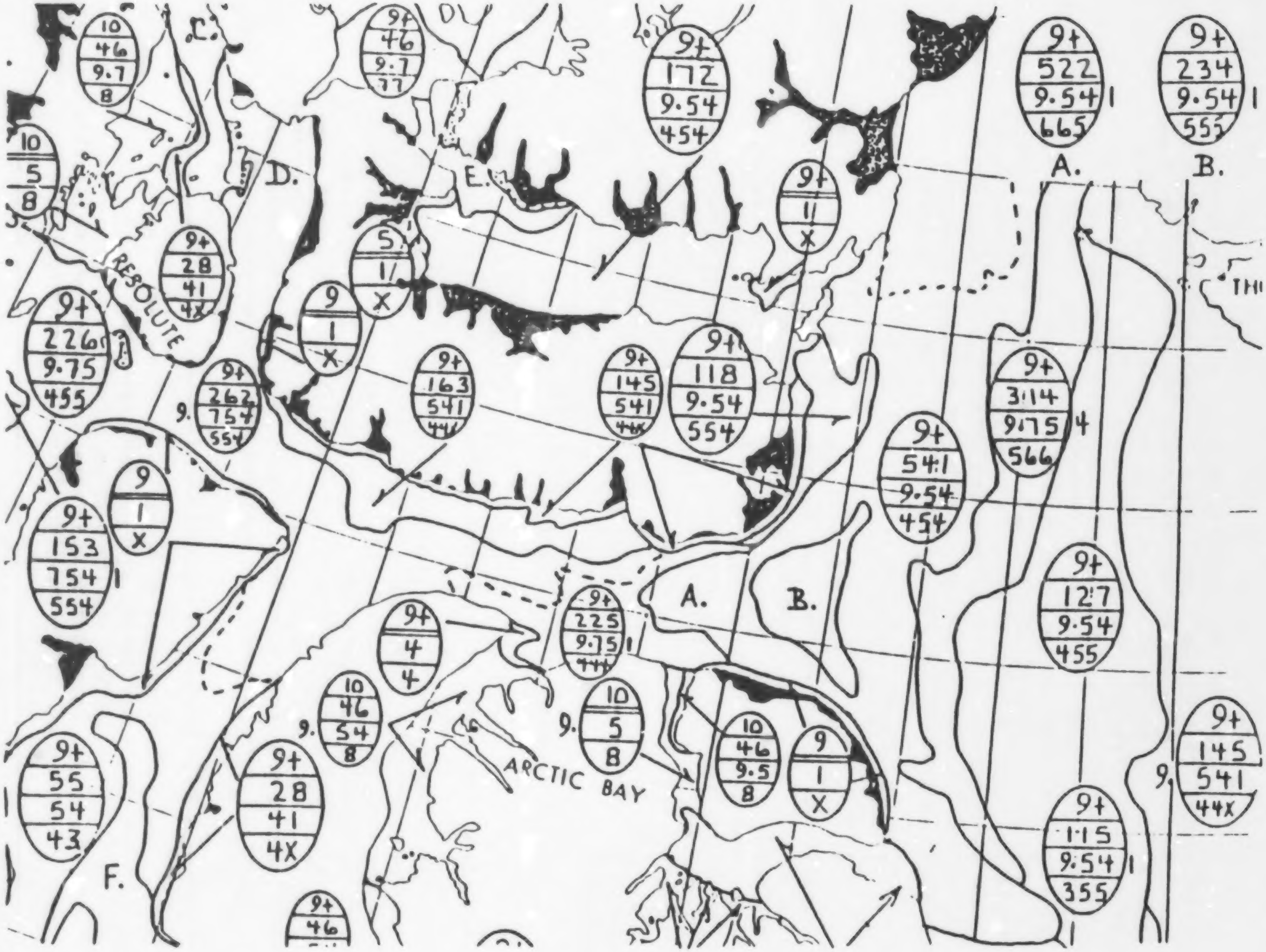
Strategic information generally provides the user with the overall ice, sea and weather conditions that will be encountered within his area of operation. This classification, however, can be misleading. For a ship travelling through the ice-infested water, there are several levels of information that may be required. Ice-no-ice, for example, is the first level of information required for route planning and may be provided by a relatively low resolution sensor. Information on ice types in a complex ice field may not be available from the same sensor. This requires a different level of support; information with tactical resolution presented on a strategic scale.

4.1.1 Weather and Ice Charts

For strategic level planning the ice and weather charts currently available from Atmospheric Environment Services and other agencies provide a first level of support. Figure 23 is a copy of a typical ice chart received by the M.V. Arctic over facsimlie circuits from AES. The ice coverage is indicated in standard notation. Figure 24 shows an ice chart of the east coast of Canada provided by the International Ice Patrol. Due to the severe communication problems in the Arctic however, these products are not always available. Furthermore, the accuracy of the predicted ice conditions is often less than desirable particularly when conditions are changing rapidly. Therefore, these information products need to be supplemented by other sources for navigating ships.

(1) Data must be timely ie. must be available to a navigating ship in near real-time.
(2) Interpretation must be accurate.
(3) Data must be available on standard marine circuits or satellite links to ship's operating in the Arctic.

Table 6 Summary of the requirements for ice and weather charts for ship's navigating in ice.



RESOLUTE
ARCTIC BAY
A.
B.
D.
E.
F.
9+ 522 9.54 665
9+ 234 9.54 555
9+ 172 9.54 454
9+ 118 9.54 554
9+ 3.14 9.75 566
9+ 541 9.54 454
9+ 127 9.54 455
9+ 115 9.54 355
9+ 145 541 44X
9+ 226 9.75 455
9+ 153 754 554
9+ 55 54 43
9+ 28 41 4X
9+ 262 754 554
9+ 163 541 44X
9+ 145 541 44X
9+ 225 9.75 44X
10 46 9.7 8
10 5 8
10 46 9.5 8
10 46 54 8
9 1 X
5 1 X
9+ 4 4
9+ 1 X

Figure 23 Typical ice chart received by the M.V. Arctic over facsimile circuit from Atmospheric Environmental Services.

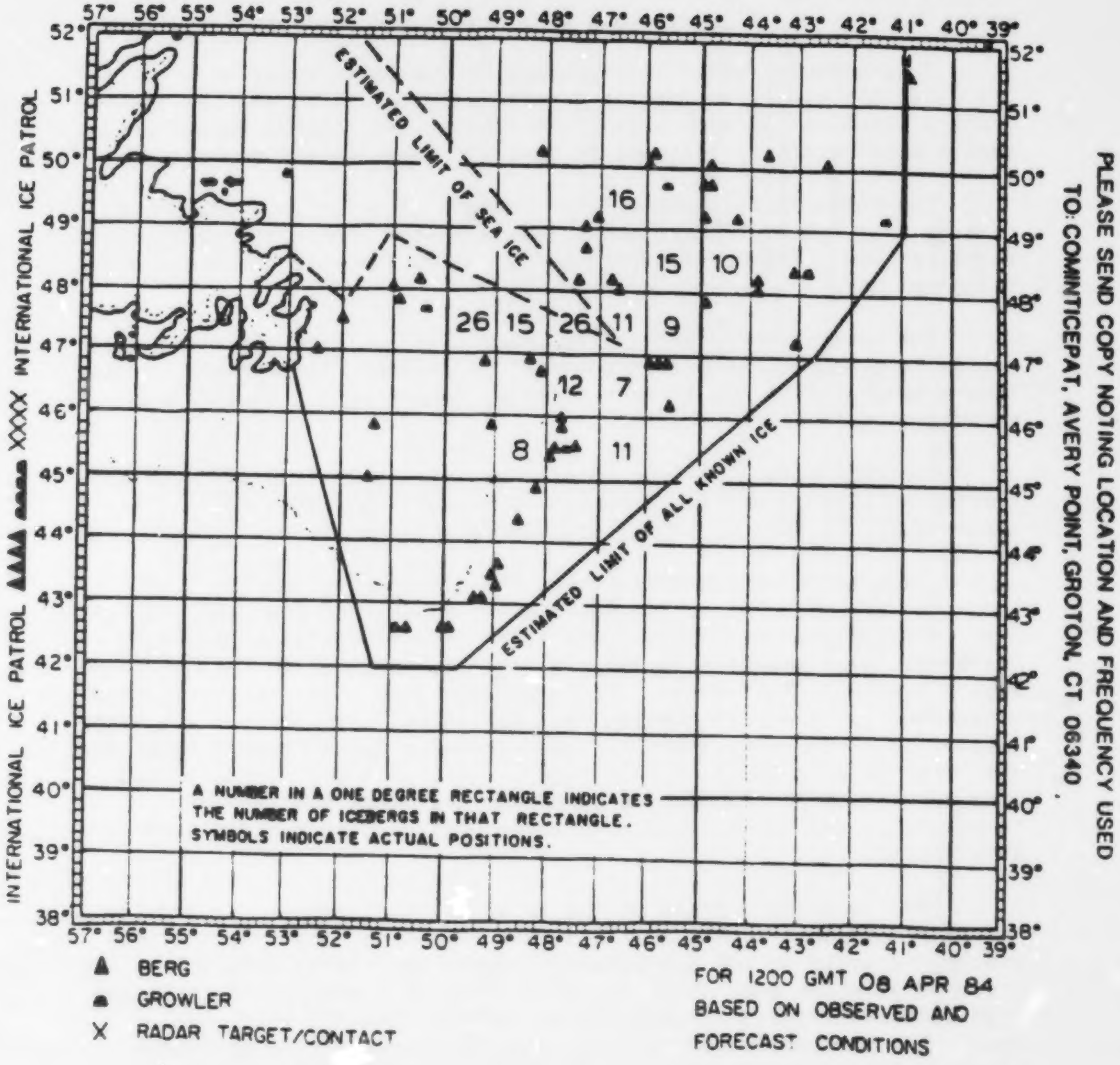

57° 56° 55° 54° 53° 52° 51° 50° 49° 48° 47° 46° 45° 44° 43° 42° 41° 40° 39°
52° 51° 50° 49° 48° 47° 46° 45° 44° 43° 42° 41° 40° 39° 38°
INTERNATIONAL ICE PATROL XXXX INTERNATIONAL ICE PATROL
ESTIMATED LIMIT OF SEA ICE
ESTIMATED LIMIT OF ALL KNOWN ICE
16
15
10
26
15
26
11
9
12
7
8
11
A NUMBER IN A ONE DEGREE RECTANGLE INDICATES THE NUMBER OF ICEBERGS IN THAT RECTANGLE. SYMBOLS INDICATE ACTUAL POSITIONS.
PLEASE SEND COPY NOTING LOCATION AND FREQUENCY USED TO: COMINTICEPAT, AVERY POINT, GROTON, CT 06340.
▲ BERG
● GROWLER
X RADAR TARGET/CONTACT
FOR 1200 GMT 08 APR 84
BASED ON OBSERVED AND FORECAST CONDITIONS

Figure 24 Typical ice chart provided by the International Ice Patrol of the East Coast of Canada.

4.1.2 Satellite Receivers

A satellite receiver such as that sold by Muirhead Systems Limited can be used to receive direct readout real-time satellite imagery from polar orbiting satellites on VHF frequencies. The Muirhead interactive display system receives the automatic picture transmissions from the NOAA 7 and 8 satellites, stores these data on a small computer and displays data on a colour RGB monitor.

Environmental satellites operate in two basic types of orbits: (1) Polar Orbiting (inclination generally 90 to 115°); and (2) Geostationary (inclination near 0°). Both imagery and digital quantitative data are collected by instruments on-board these satellites [4].

The Polar Orbiting satellites operate in relatively low orbits ranging from 700 to 1700 km above the earth and circle the earth 12-14 times per day. The orbits are timed to allow complete global coverage twice per day.

The Geostationery satellites operate in a higher orbit and their motion is synchronized with the earth's rotation. Their field of view covers about 25% of the earth's surface, generally 50° of latitude north and south of the equator.

The NOAA polar orbiting satellites began with TIROS in 1960 and reached a third generation with the launch of TIROS-N in 1978. This was followed by NOAA 6, NOAA 7 and NOAA 8 (Figure 25).

The primary instruments aboard the NOAA satellites are the Advanced Very High Resolution Radiometer (AVHRR) and the TIROS Operational Vertical Sounder (TOVS). The AVHRR is a five channel scanning radiometer with channels in the visible, visible-near IR, and IR water vapour window. It produces 1 km resolution data that are transmitted continuously. The TOVS complex includes three instruments - the High Resolution IR Sounder (HIRS-2) - the Microwave Sounding Unit (MSU) and the Stratospheric Sounding Unit (SSU). TOVS data are commonly used for; derivation of atmospheric soundings, vertical profiles of temperatures and humidity, and to correct AVHRR data for atmospheric attenuation.

Data relaying systems on the polar-orbiting satellites provide raw data readout of AVHRR and TOVS data to ground receiving stations around the world on VHF and S-band frequencies. AVHRR data are provided as a low resolution Automatic Picture Transmission (APT) and High Resolution Picture Transmission (HRPT). The APT which has a resolution of 4 km is sent on VHF; the HRPT; however, is an S-band signal. TOVS data are received on both VHF and S-band. Figure 26 is a HRPT image of Lancaster Sound recorded from a NOAA satellite.

The advantage of direct readout systems like Muirhead's is that real-time data are easily received anywhere in the Arctic. The disadvantage of IR/visible satellite data, or course, is that ice information is only available under favourable atmospheric conditions i.e. when there is little or no cloud cover. The Muirhead system receives the reduced resolution (4 km) APT data product on VHF. It does not georeference the imagery, however, so it is often difficult to identify the images displayed if they are partially obscured by clouds.

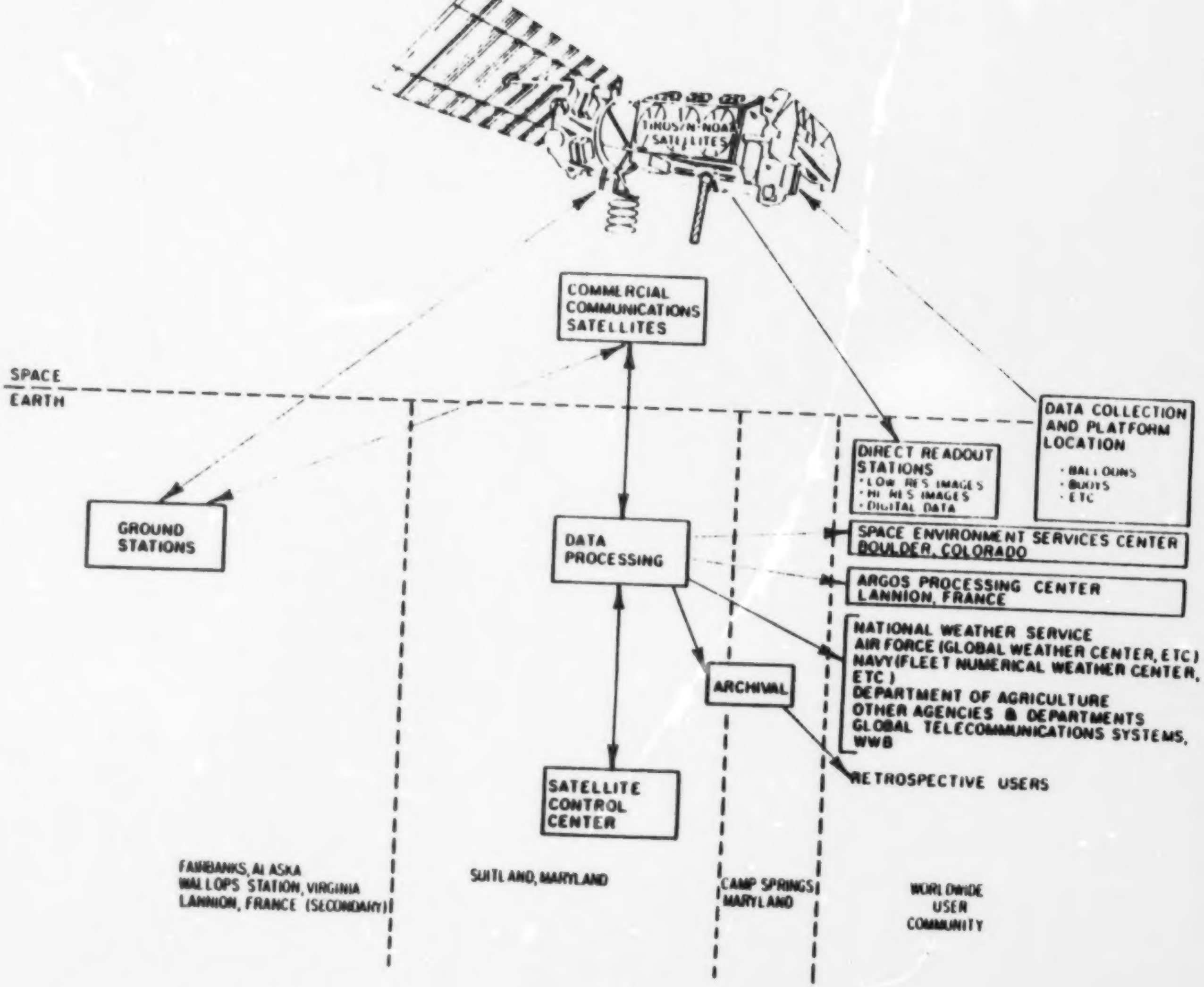

TIROS/N-NOAA SATELLITES
COMMERCIAL COMMUNICATIONS SATELLITES
SPACE
EARTH
GROUND STATIONS
DATA PROCESSING
SATELLITE CONTROL CENTER
ARCHIVAL
DIRECT READOUT STATIONS
· LOW RES IMAGES
· HI RES IMAGES
· DIGITAL DATA
DATA COLLECTION AND PLATFORM LOCATION
· BALLOONS
· BUOYS
· ETC
SPACE ENVIRONMENT SERVICES CENTER BOULDER, COLORADO
ARGOS PROCESSING CENTER LANNION, FRANCE
NATIONAL WEATHER SERVICE
AIR FORCE (GLOBAL WEATHER CENTER, ETC)
NAVY (FLEET NUMERICAL WEATHER CENTER, ETC)
DEPARTMENT OF AGRICULTURE
OTHER AGENCIES & DEPARTMENTS
GLOBAL TELECOMMUNICATIONS SYSTEMS, WWB
RETROSPECTIVE USERS
FAIRBANKS, ALASKA
WALLOPS STATION, VIRGINIA
LANNION, FRANCE (SECONDARY)
SUITLAND, MARYLAND
CAMP SPRINGS MARYLAND
WORLDWIDE USER COMMUNITY

Figure 25 TIROS-N Spacecraft and data flow.

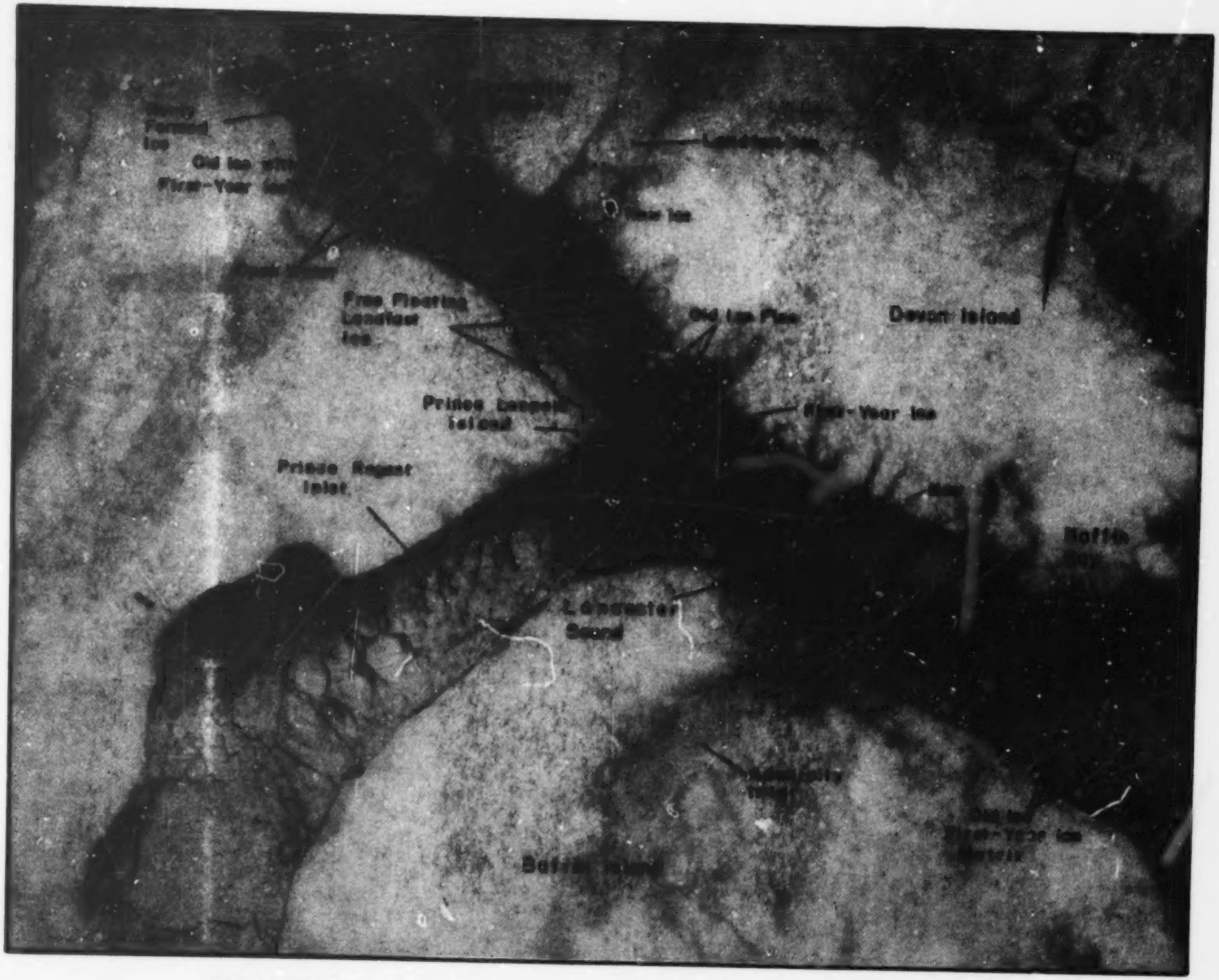

Newly Formed Ice
Old Ice with First-Year Ice
Landfast Ice
Floe Ice
Free Floating Landfast Ice
Old Ice Floe
Devon Island
Prince Leopold Island
First-Year Ice
Prince Regent Inlet
Baffin Bay
Lancaster Sound
Baffin Island

Figure 26 A high resolution image of Lancaster Sound recorded from a NOAA satellite.

In addition, the images received are also not geometrically corrected in any way so interpretation often requires a skilled operator.

There is no question that these kinds of systems will be an essential part of MIDAS. The receiver installed on-board the M.V. Arctic has not operated reliably nor long enough to make a complete evaluation and it is premature to specify requirements; more study is needed. The satellite receiver though, should be capable of automatically receiving and storing transmissions from a number of sensors and platforms. The TIROS-N/NOAA satellites currently provide a number of direct readout products which have proven to be useful for marine operations in the Arctic. (These spacecraft and sensor components are described in detail elsewhere [5,6]). The system should allow the user to display these data with a minimum of effort. The images displayed should also be georeferenced (i.e., annotated with latitude and longitude information). The system should be capable of displaying data at several levels of resolution and there should be a number of image processing algorithms available to enhance the displayed data. The degree of image processing required will depend to some extent on the sensor. The IR/visible products received by the Muirhead system for example are not stretched, gridded or rectified.

A colour display may also be required for enhancement and analysis so the video signal should be RGB (red, green, blue). The system should also have a means of communicating with other computers so that image data can be made available to other systems for further processing or analysis. These requirements are summarized in Table 7.

---

(1) System must be capable of automatically receiving and storing satellite IR/visible transmissions from polar satellites.
(2) System should allow user to display data with a minimum of effort at full resolution.
(3) Images displayed should be annotated with latitude and longitude information.
(4) Image processing algorithms should be available to enhance and connect raw data where necessary to aid interpretation.

Table 7 Requirements for a real-time satellite receiver station for a shipboard ice navigation system.

4.1.3 Airborne Radar

Due to the problems with reception and the question of reliability with the previous sources of strategic information mentioned, airborne radar is also required for totally reliable strategic support for Arctic operations. Radar is able to extend the data collection window since it is not hampered by cloud cover or darkness [7]. It is real-time, high resolution, relatively inexpensive and can be easily transmitted to a ship in transit.

4.1.3.1 Downlink Operation

It was demonstrated on the M.V. Arctic that airborne radar imagery made available to the ship in real-time or near real-time by radio downlink can be effectively utilized for tactical and strategic ice navigation. The current downlink being used by INTERA operates at a VHF frequency 219.5 MHz. It is line of sight communication, that is, the aircraft must be seen by the antenna of the receiver on board the ship. The downlink will work with STAR-1 flying at an altitude of roughly 10,000 metres, out to a practical limit of approximately 200 nautical miles.

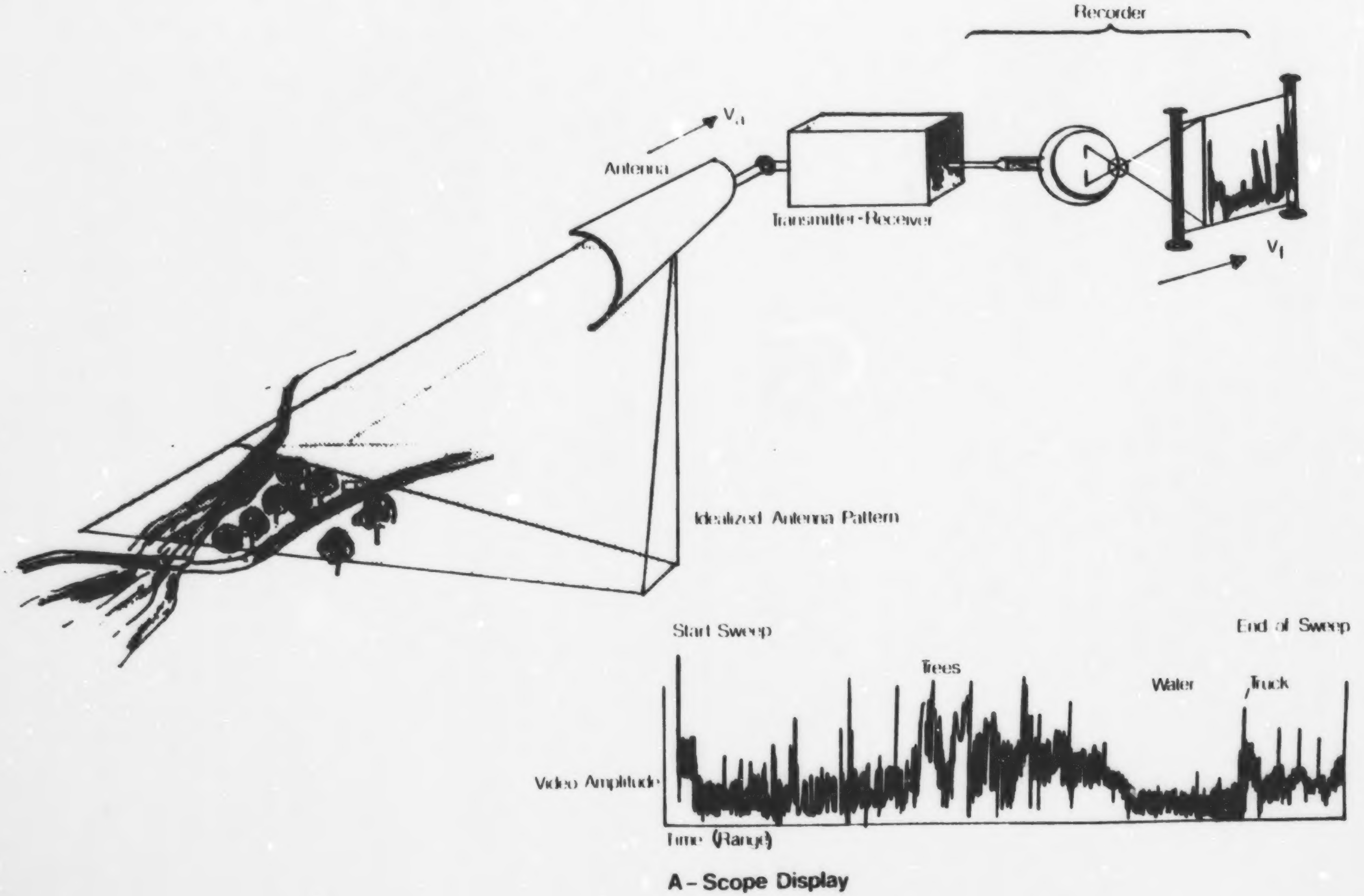
Another technique for downlinking that has been used by INTERA on occasion is to drop imagery to ships working in a more regional or site specific area. While this has been used as a means of communicating with ships on a casual basis where the data delivery is a one time operation, this has also been used with success on a semi-routine basis on land-based operations. It is not a recommended solution though, for vessels in transit.

A new approach is being adopted by INTERA for downlinking when the aircraft is beyond the range of the receiver. First imagery will be recorded on board the aircraft on HDDT tapes. Provision is being made to record that imagery at slightly reduced resolution; instead of recording at 12 x 12 meters (normal) resolution; it is recorded at 24 x 24 meter resolution. The main advantage is this allows the aircraft to loiter within downlink range of the ship and send the imagery down at four times the current speed. The result is the aircraft does not need to loiter hour for hour over the ship in order to downlink imagery. Experience in June of 1984 showed that loitering time seriously constrained the ability of STAR-1 to collect and deliver imagery to the ship at ranges greater than 200 nautical miles.

INTERA currently has no plans to modify the downlink frequencies to S-band. Inquiries with the Department of Communications have led us to believe that for high Arctic use, 219.5 MHz will be available, for the next five to ten years.

4.1.3.2 SLAR

Side looking airborne radars (SLAR's) have traditionally been used to provide wide area coverage (50-100 km per side) of the Arctic ice. Such systems are operated both by government and by private companies. It has been demonstrated that SLAR imagery can provide valuable information on ice conditions. Ice classification is made on the basis of tone, texture and context of the data. SLARs (Side Looking Airborne Radar) are basically marine radars which look sideways out of an aircraft (Figure 27). Instead of having a PPI display where the scan goes round and round, they have a static single line display along which a film is pulled thereby building up an image of the terrain along the side of the aircraft. This produces a strip map compared to a marine radar which produces a plan position map. The range resolution of a standard marine radar or SLAR system is usually relatively course (of the order of 25 metres). It is desirable to have



Recorder
V_a
Antenna
Transmitter-Receiver
V_f
Idealized Antenna Pattern
Start Sweep
End of Sweep
Trees
Water
Truck
Video Amplitude
Time (Range)
A-Scope Display

Figure 27 Typical side-looking radar system.

a high power pulse to achieve farther maximum ranges. A very high powered and very short pulse radar however requires a very sophisicated electronic system, therefore, cost tends to limit the SLAR resolution at practical ranges to about 25 meters. The azimuth resolution of a standard SLAR is limited by the length of the antenna. Practically, antennas longer than 3 to 4 meters are beyond the capability of most aircraft to carry. The solution to improved range resolution or improved azimuth resolution is relatively expensive and in fact results in the SLAR being converted to a SAR [8].

The image quality achieved with a SLAR also depends upon exactly how closely the flight line of the aircraft approximates a perfectly straight line. Typically aircraft have a crab angle because the desired track is not colinear with the wind. Also aircraft typically exhibit yaw, (roll and pitch relative to their desired flight line). The older radars, of the type used by AES, (namely the APS 94D,) have a motion compensation system which is a mixture of rotating the trace on the cathode ray tube (CRT) so that the data are written onto the film in a yawed mode comparable to the crab angle of the aircraft and a motion compensation for high frequency variations which actually moves the antenna. This results in a rather expensive large and heavy antenna mount which requires an aircraft of the order of the Electras flown by AES. To compensate for the roll and pitch of the aircraft (which basically do not effect the image geometry but only the radiometric quality of the imagery), these SLARs have an electronically modulated sensitivity time control (STC) curve. This results in an image which has been corrected both radiometrically and geometrically for the motions of the aircraft. The quality of this correction will determine the radiometric fidelity of the resulting image. Typically, because the radiometric reflectivity of the ground varies over a fairly large range, SLARs have tremendous difficulty in maintaining good radiometric fidelity over the entire swath and from one end of the line to the next. Quality operators are therefore required to ensure high quality data.

The SLAR used by INTERA uses a very different approach to motion compensation. The image data are digitized immediately after the receiver; and all motion compensation is done and all sensitivity control corrections are done using a digital correction. The yaw compensation and crab angle removal are performed in a large digital memory. The data are written in at an angle corresponding to the crab and yaw of the aircraft and are read out comparable to a line perpendicular to the desired flight path of the aircraft. Similarly, roll variations and other STC corrections are done in the digital memory by applying a look-up table (which is programmable). The main advantage over the older systems is that the system is both lighter and therefore much cheaper to fly; as it can be flown in a much smaller aircraft like the Cessna Conquest. An additional advantage is that when a downlink is attached to the radar the data are pre-corrected. With the APS 94 the downlink data are typically not corrected for crab angle variations.

A problem with using SLAR systems for ice navigation relates to the reflectivity variations of ice with respect to the depression or incidence angle at which the radiation strikes the ice. Typically, the reflectivity of undeformed sea ice falls off for first-year ice from approximately -10 db at 10° depression angle to approximately-25 db at 70° depression angle in a more or less linear fashion. Multi-year ice is typically 8 to 10 db brighter than first-year ice. However, from 70° to 80° the reflectivity drops much more rapidly, and from 80° to 90° essentially goes to zero. That means that the reflectivity of ice below approximately 10° depression angle begins to fall off very rapidly. For SLARs that means that to achieve a wide swath and good radiometric image fidelity it is necessary to fly at relatively high altitudes. This means that the azimuthal resolution, which is a function of the distance from the plane to the terrain, becomes relatively poor at far ranges. It also requires the aircraft to fly at altitudes which are typically impractical for visual reconnaisance.

Experience has shown that the APS 94D when flown by the AES at 7,000 feet cannot successfully produce quality imagery for strategic and tactical navigation purposes, at ranges beyond 20 km. This has led INTERA to adopt a 25 km swath width maximum per side when flying at 16,000 feet to produce relatively good imagey. However, the imagery is at best marginal for close hazard detection and tactical support. It really is most useful for gross ice feature detection, large feature tracking and ice-no-ice boundary detection. The principle attraction for SLAR over SAR is its rather low equipment cost and therefore, low user cost. A summary of the basic requirements for a SLAR system which could be used for ice navigation tasks by a navigating ship are listed in Table 8.

(1) Recorded data must be in digital format so that it can be telemetered easily from aircraft to ship.
(2) High quality motion compensation required onboard aircraft to pre correct data before transmission.
(3) Aircraft should fly at high altitudes approx. 16,000 ft.
(4) Requires trained operators to ensure radiometric fidelity of data.
(5) System should be operated in narrow swath (25 km per side) mode for unambiguous ice information.
(6) Georegerencing of data would be useful.

Table 8 Basic requirements for a SLAR system to be used for ice navigation.

4.1.3.3 SAR

Experience gained on the M.V. Arctic has shown that a high resoluiton airborne radar that is capable of making unambiguous ice classification is required for tactical support in difficult ice conditions. INTERA's STAR-1 SAR is such a system since it achieves a resolution of a few metres. This SAR has excellent radiometric characteristics and shows a much greater consistency of returns that SLAR.

While the SLAR was described as being a marine radar looking sideways a SAR could be described as a dramatically upgraded SLAR. The azimuthal resolution of a SAR is improved by post flight processing. In the case of INTERA's STAR-1 post flight means one or two seconds after passing a target. A doppler history is recorded for a target as the aircraft passes by and by using a technique called doppler compression, a point image is created from that doppler history. The result is azimuthal resolution whose effective limit is the processing power chosen on board the aircraft and it is independent of range. The INTERA STAR-1 SAR has an along track or azimuthal resolution of approximately 6 metres, independent of range. Similarly, the cross track range is a function of signal processing as well. The maximum power transmitted is also relatively low. Pulse lengths which are physically very long, after processing, are very short resulting in relatively fine range resolution. For the INTERA STAR-1, this is 6 or 12 metres range resolution depending upon the mode selected, (that is 25 or 50 km swath width). The price paid for this dramatically improved image quality is a very much more complicated radar transmitter, receiver and digital processor on board the aircraft. The motion in this system must also be much better than the average SLAR or a high quality picture cannot be created. Therefore a typical SAR image will have crab angle and yaw, roll and pitch variations removed from the image before it is created.

Because the SAR has a large degree of gain in the coherent processor, most of the radar's gain is digitally controlled. Therefore the radiometric properties of the image are much more easily controlled than with a SLAR. The result is, not only is the image resolution dramatically improved and stabilized for the entire image, but radiometric fidelity of the image across track and along track is also very good.

One advantage of having range independent resolution is that providing sufficient power can be obtained to illuminate the scene, the aircraft can fly as high as is practical and look out as far as is practical, and still achieve the same resolution. This allows much greater control over depression angles with which the scene is viewed than with a SLAR. The logical extreme is to put a radar in a satellite as was done with SEASAT and is proposed for Canada's RADARSAT. However, other problems such as complex receivers and image processing make them less than optimum for real-time tactical navigation purposes. STAR-1 typically flies at 10 to 11,000 metres above sea level and can thus have a full 50 km swath over a range of depression angles from approximately 30° to about 7° at 50 km swath width. This is the region for which it is relatively easy to compensate for the reflectivity variations of the ice by using an STC look-up table in the real-time process. The result is uniform ice characteristics over the entire swath with no contrast inversions between different types and no loss of information about distributed ice forms. It has been noted that SAR or SLAR when flown at very shallow depression angles will only image deformed ice essentially producing a map of the ridges which looks very much like a marine radar image.

SAR has shown itself to be a nearly ideal sensor for tactical and close tactical ice navigation support during experiments conducted with STAR-1 and the M.V. Arctic.

The SAR data provide an accurate map of the ice conditions in sufficient detail to steer the ship. That is individual ridges and rubble areas, small old floes, small bergs in first year ice, and areas of open water are all detectable. The radiometric characteristics are such that no grey scale classifiers or spatial feature extraction techniques are required for interpretation, though they may be desirable in the future as an aid to untrained observers. The imagery can generally be used directly as a map by ship's officers. SLAR data on the other hand, are not so consistent and often require a specially trained person for interpretation. Figures 28 and 29 show a comparison of SAR and SLAR imagery taken of the same area in Lancaster Sound. Notice the much greater rediometric fidelity and dynamic range present in the SAR data.

The details of INTERA's STAR-1 SAR are summarized in Table 9. The aircraft speed and endurance are such that the entire Northwest Passage, Lancaster Sound, Baffin Bay or the Labrador coast can be mapped in a single flight. This can later be downlinked to a ship directly from the aircraft. Thus STAR-1 can provide tactical level information on a strategic scale; wide areas can be viewed at much reduced resolution without excessive loss of information. INTERA's studies have shown that data reduction to 24 m x 24 pixels can take place before there is any significant loss of information. Further reduction yields some loss of textural information though the data may still be suitable for strategic support.

4.2 Tactical Information

Ships operating in ice require high resolution data that can be presented in the order of metres if they are to successfully avoid the hazards along their route. Satellite systems are unable to provide this kind of resolution so the current tactical tools available are primarily restricted to airborne sensors and ships marine radar. As newer systems such as sonar prove to be useful, they will have to be incorporated into MIDAS.

4.2.1 Airborne Radar

Experience gained with operators in the Beaufort Sea coupled with results of experiments conducted on the M.V. Arctic have shown that high resolution airborne radar imagery downlinked to the bridge of a ship provides an excellent tactical navigational tool when used along with marine radar. Both SAR and SLAR have been evaluated.

4.2.1.1 SLAR

Experiments conducted on board the M.V. Arctic with the use of SLAR data have shown that SLAR, when used in conjunction with marine radar, can provide tactical support for vessels. This support however, depends on several factors which include:

i. The ice conditions - SLAR data can be useful when ice conditions are such that interpretation is rather straightforward. This might be, for example, ice-no-ice conditions that exist during spring breakup. For more complex ice conditions, however, SLAR is only marginally acceptable.

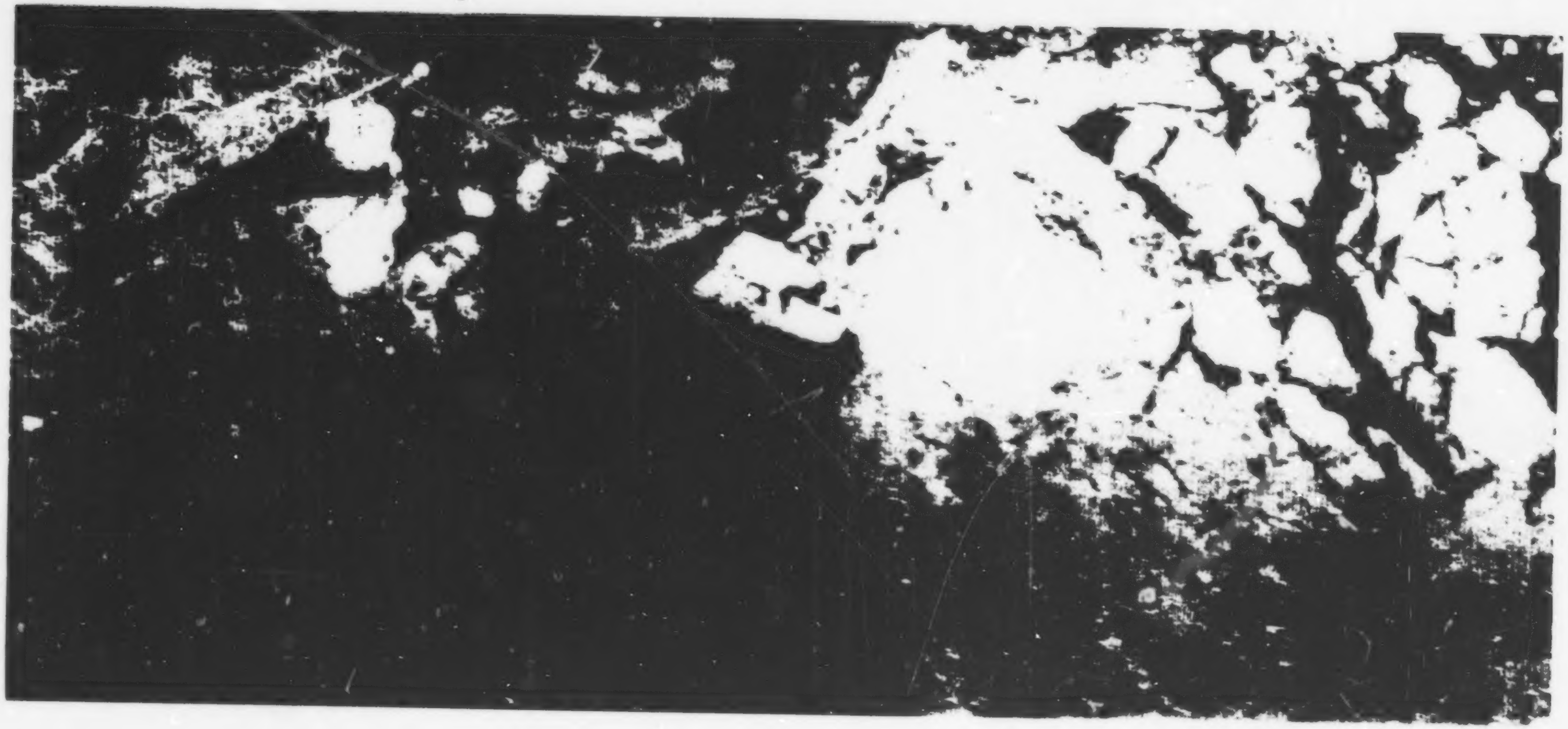


Figure 28 A typical INTERA SLAR image of the ice conditions that exist during the fall in Lancaster Sound.

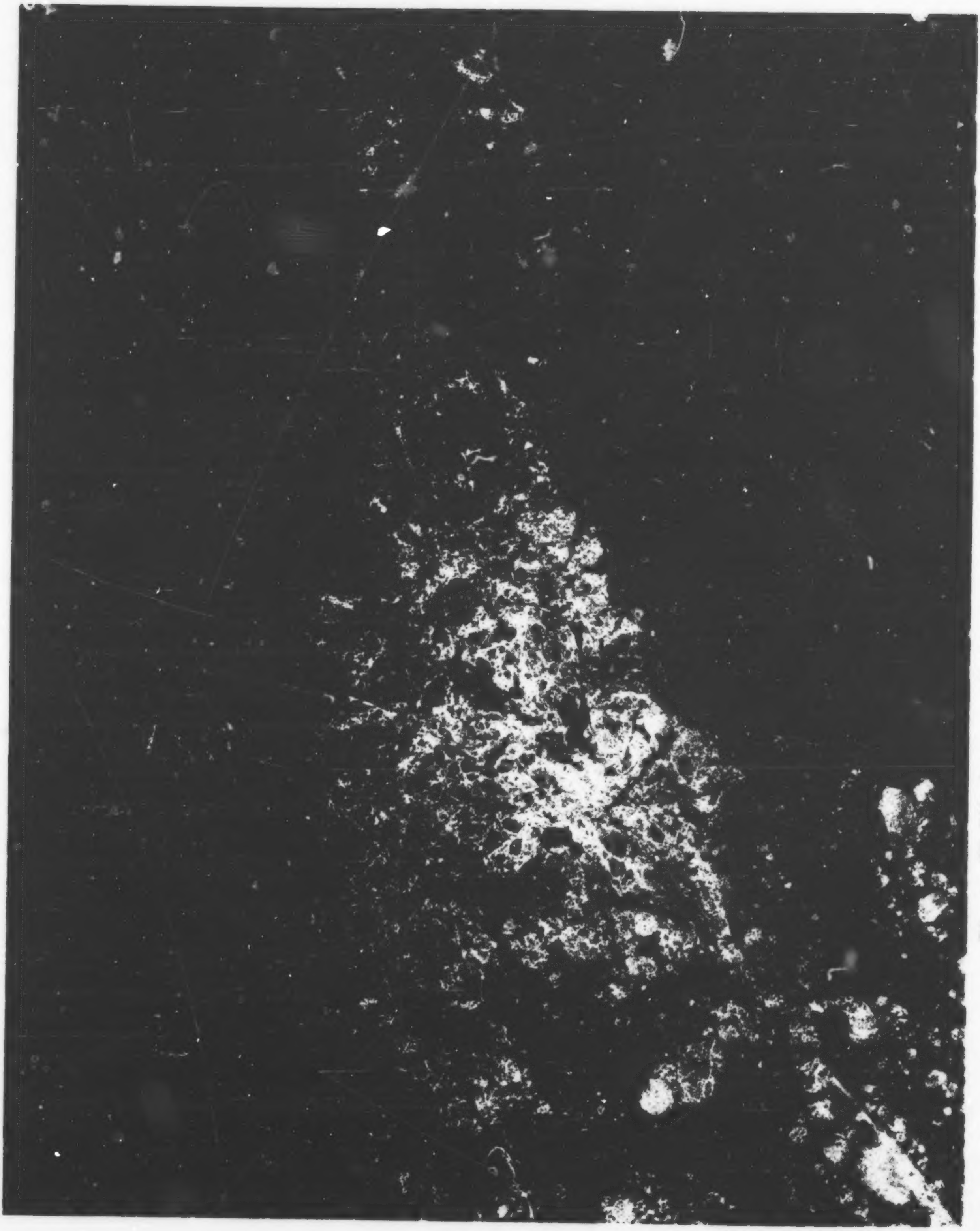


Figure 29 SAR imagery of the ice conditions that exist during the fall in Lancaster Sound. This image is of the same area as the previous SLAR scene. Note the much greater radiometric fidelity of this image.

STAR-1: A HIGH-RESOLUTION SYNTHETIC APERTURE RADAR

The STAR-1 system has been designed to meet standards of economy, effectiveness, lightweight portability and flexibility in operations. By applying advanced electronics technology, it is now possible to build radar systems that exceed the performance of the old systems at a fraction of the size and weight, which allows installation in a much smaller aircraft and consequent reduction of aircraft operation costs. In-house development activities have been kept to a minimum by using off-the-shelf microtechnology whenever possible.

The basic system parameters for STAR-1 are as follows:

Frequency: X Band (3 cm wavelength)

Polarization: HH, parallel

Resolution:

Resolution		Swath Width
range:	6 m	
azimuth:	6 m	25 km
range:	12 m	
azimuth:	6 m	50 km

Number of Looks: 7

Weight: 450 kg, including antenna and recording systems

The radar payload has been designed to fit in an aircraft such as a Cessna Conquest twin turboprop. This aircraft has an operational ceiling of 33 000 ft above sea level and a typical flight endurance of six hours, making it quite suitable for missions over targets in remote areas.

The data products and replay capabilities include a digital radar interface for on-board, real-time display and digital recording, as well as the capability to downlink a digital data stream in near-real time to a ground-based receiving station. Operational services are expected to start in October 1983.

Table 9 INTERA's STAR-1 Aircraft Parameters.

ii. The quality of the SLAR - There are several technical problems that make it extremely difficult to produce a high quality SLAR image that is virtually free of image distortions. Some of these conditions have been discussed in the previous section and include aircraft yaw and motion instability, and depression angle.

3. The training of the ship's personnel and their familiarity with SLAR - due to the problems inherent in most SLARs reliable interpretation can only be made by experienced ice observers. Thus most ships' personnel are unable to use uninterpreted SLAR imagery directly as an ice map for navigation.

4.2.1.2 SAR

It has been demonstrated that high resolution SAR imagery provides unequalled tactical level support for ships navigating in ice. It provides an accurate map of the ice conditions in the vicinity of the ship in sufficient detail to provide steering information to the ship's commanders when used along with the marine radar. It can usually be interpreted directly by ship's personnel who have very little formal training in the interpretation of imagery.

The shipborne equipment that was used to receive and display INTERA's SAR imagery for the field trials produced a hard copy product. This product has been adequate for most applications, however, it does not present STAR-1 data at full resolution and has a limited number of grey scales available. In very difficult ice conditions, the observers on the M.V. Arctic attempted to improve the resolution of the hardcopy product by enlarging the image transparencies with an optical projection system. This was somewhat successful but a better solution can easily be implemented by using a high quality video monitor to display the full resolution data. One STAR-1 line of data consists of 2048 words of 4096 bytes. Each image pixel consists of 8 bits or one byte therefore, there are 4096 pixels of STAR-1 data in the range direction. Most RGB monitors provide a horizontal resolution of about 600 pixels. Ultra high resolution monitors with 13 and 19 inch screens can now be obtained with 1000 by 1000 pixel resolution. Although these systems limit the amount of full resolution, STAR-1 imagery that can be displayed at any one time, they make it possible to display all the information contained in the digital radar data. This display can also be either in black and white or colour.

One of the problems with INTERA's existing downlink receiver is that data reception is a full time task that requires a skilled operator. This involves among other things coordinating the data transfer with the aircraft, adjusting the receiver line rate, setting the intensity levels of the fibre optic plotter and changing magnetic tapes. To ease the work load on the ship's personnel it is better that for MIDAS, this operation be done automatically with little or no operator intervention.

A major problem with the use of INTERA's SAR and SLAR data for tactical navigation is that there is no georeferencing on the imagery. The latitude, longitude, heading and other aircraft flight parameters are passed via radio to the ship. From this information, the latitude and longitude of the image strips can be computed. This is a slow process which can easily result in errors so MIDAS requires that the airborne radar be georeferenced. This task can easily be accomplished by embedding the aircraft's Inertial Navigation System (INS) coordinate information and flight parameters in the downlink data stream. This information would then be available to the ground station and would be used by the receiver station to calculate and display a latitude and longitude grid on the imagery.The basic requirements for a SAR system which will support ice navigation are summarized in Table 10.

---

(1) Recorded data must be in digital format so that it can be telemetered easily from aircraft to ship.
(2) Data should be precorrected for motion compensation before transmission.
(3) Aircraft should fly at high altitude (10,000 m) for uniform illumination of sea ice.
(4) 12 x 12 m ground pixels required for close tactical navigation in heavy ice.
(5) 24 x 24 m ground pixels adequate for strategic and tactical navigation tasks.
(6) The imagery should be georeferenced to aid ice navigation.
(7) The high resolution radar data must be available to ship's personnel in any easy to use format.

Table 10 Basic requirements for a SAR system to be used to support ice navigation.

4.2.3 Marine Radar

A significant problem with using airborne radar imagery for tactical navigation is identifying the ship's position on the imagery. Keeping track of the ship's progress through the ice is also a complex task and generally the only sensor capable of accomplishing these tasks is the ship's own marine radar.

For tactical navigation Marine radar provides the much needed connection between where the ice is at the time of the ship's passage and where it was when the airborne imagery was collected. By constantly tracking the ship's position in the airborne ice image with the marine radar, the airborne radar imagery can be used to steer the ship and avoid hazards.

The conventional marine radar consists of three main components; the scanner, the transceiver, and the display (Figure 30). For the most part, marine radar systems have been designed to provide optimum target (i.e., other ships, navigation buoys, etc.) detection in sea clutter and foul weather [9]. They are designed to provide very

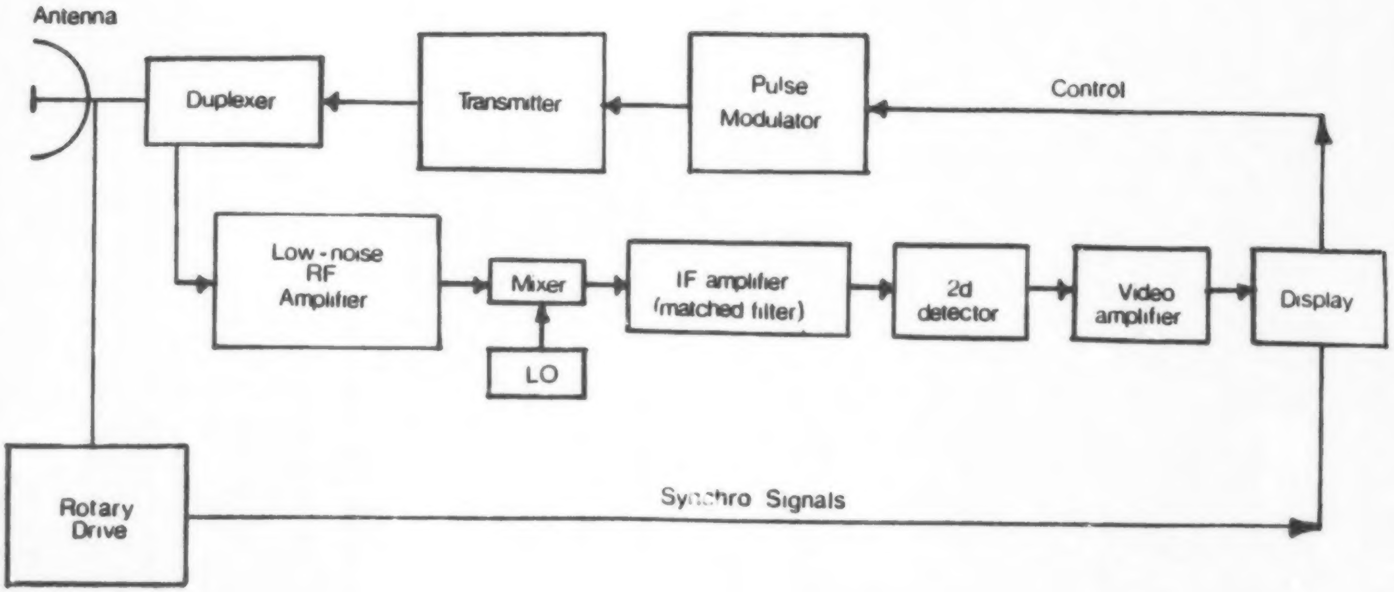

Antenna
Duplexer
Transmitter
Pulse Modulator
Control
Low-noise RF Amplifier
Mixer
LO
IF amplifier (matched filter)
2d detector
Video amplifier
Display
Rotary Drive
Synchro Signals

Figure 30 Block diagram of a typical marine radar system.

reliable service, and to be easily repaired. They use very conventional technology and are sold to a very cost conscious and relatively non-technical clientele. Little or no effort is included in the average radar design for tracking the ship's location in a complex ice field.

4.2.3.1 Ice Navigation with Marine Radars

For conventional navigation tasks, the marine radar has become the prime source of close tactical and tactical information. From the ice navigation viewpoint, however, it has too limited a range for practical route selection. Thus, the main task, for the marine radar, when in heavy ice, has become to locate and track the ship's progress on airborne radar imagery. In the presence of icebergs, or very low concentrations of ice, the target detection capability is of the utmost importance.

There are three basic requirements for an ice navigation radar. First it must be able to detect weak targets at far range. Second, it should be able to detect targets in the presence of both sea clutter and bad weather. These are both aims of conventional radars. Third and unique to this application, the radar must be capable of making a 'picture' of the ice for comparison with the airborne radar imagery. It must be capable of producing an image of the ice that has range dependent gain removed so ice type signatures are stable over the near ranges. It should contain the maximum electronic signal to noise enhancements possible, consistent with the picture quality being maintained. It should also provide the maximum possible coverage of the ice imagery, to permit registration with the SAR/SLAR imagery. This means retaining past imagery in a useful form for correlation.

4.2.3.2 Conventional Marine Radars and Ice Navigation

The marine radar is generally divided into three functional elements; the scanner, the transceiver and the display. The scanner consists of the antenna, the motor to turn it, and the associated bearings, mountings, etc. The transceiver contains the transmitter, receiver, complete to the video level, and associated power supplies. The display has the operator controls, the actual display tube and associated power supplies and signal conditioning electronics.

-The Scanner: The antenna on a standard marine radar will be some 2 to 3 metres long for X-band, or perhaps as long as 4 metres for S-band. The main advantage of S-band is a claim of an improved ability to penetrate heavy rain, which is not normally found in the Arctic. Recent studies by Haykin et al [10] have shown that S-band radars may produce images more clearly showing returns from physically significant targets. However S-band is poorer at detecting low-lying targets than X-band. We will limit our discussion to X-band radars.

A 3 metre antenna (with a beam width of approximately 0.7 degrees) has, at X-band, a gain of about 30 db. The gain could be much higher, but the vertical beam width is kept to about 15 degrees. This is for two reasons. First to keep costs low, the antenna construction must be very simple. This generally means a single slotted waveguide, with a minimal reflector. Secondly, to ensure adequate performance on a rolling ship, the vertical beam is kept wide. For an ice monitoring radar, this beam width is not needed as in ice a ship rolls very little. Thus, the antenna beam width could be narrowed considerably, thereby increasing the gain substantially and thus the overall system performance. However, this would require a special antenna design, and would limit system performance in the open sea. It is therefore probably not a prime place to look when seeking to augment performance.

One factor which, within limits, is easily variable on a shipborne radar installation is antenna height. The general rule is "higher is better", for improved long range target detection and image formation in heavy ice. Experience with radars mounted on drilling derricks some 70 metres above sea level show large ice hazards can be detected to 40 km. It has also been shown on the M.V. Arctic that a "lower is better" radar for detecting targets in heavy ice can be used but this is only useful for very close tactical support.

If a new antenna design is to be considered, the obvious questions of polarization would come up. Since sea clutter is enhanced by vertically polarized radars, tradition dictates marine radars are horizontally polarized. Economic factors have dictated that marine antennas should also have the same transmission and reception characteristics. Scientific results from the study of radar reflectivity of sea ice has shown that cross polarized return from hazardous ice types (land ice, multi-year ice, etc.) may be enhanced with cross polarized returns. By cross polarized we mean horizontal transmit, vertical receive, or the reverse. Research on the use of cross polarized antennas is being conducted by both McMaster University and by the Canada Centre of Inland Waters [10]. The interim results are encouraging and show that under some conditions cross polarized radars may be very useful for hazard detection. However, it is not clear if the operational scenario for such radars will justify the rather higher costs of such antennae. Both the operational scenarios and the expected relative performance of cross and like polarized radars needs further definition.

-The Transceiver: The transceiver of a standard marine radar is a very careful balance between cost/sophistication, reliability and performance. The two parts, transmitter and receiver are carefully matched to each other. Transmitters are usually magnetrons at X-band frequencies. For a relatively modest increase in cost, the transmitter power available in the cheapest marine radars, can be increased by almost an order of magnitude. Typical powers of 50-100 kw are available from standard radars.

The most obvious enhancement to be made to the transmitter is to change the magnetron to a "coherent" source. This allows signal processing to be applied which can distinguish returns from moving targets. Coherent radars have been very effective in air traffic control and military surveillance tasks. However, the very significant increase in cost (a factor of 25 or more) has yet to be justified for an ice marine radar. Again McMaster Univerisy has been examining this issue, and has begun the construction of an experimental radar with which to study the utility of coherent radars.

The standard receiver, in recent years, has come to be a logarithmic amplifier followed by superheterodyne receiver. Recent developments in high quality low noise X-band amplifiers has shown that a 5-6 db improvement in radar S/N can be obtained, for a relatively modest expense. This represents a 4 fold increase in transmitted power. While careful selection of the amplifier is essential to avoid unacceptable limits on system dynamic range (resulting in saturation of near range ice targets), the use of low noise RF amplifers is to be encouraged for ice navigation tasks.

-The Display: The third segment of the marine radar, the display, is the one where, in INTERA's experience, there is the greatest potential for cost effective improvements on marine radars, for ice navigation tasks. The standard display is the Plan Position Indicator (PPI). The video is displayed on a cathode ray tube, with a very carefully selected phosphor. The display also has several electronic signal processing options built in, which have evolved, over the years, to aid in ship navigation. There is a variable gain control, to compensate for range dependent gain (S.T.C.). There is a form of high pass filter (F.T.C.) to remove rain and some sea clutter. There is also a form of constant false alarm rate threshold circuit. The phosphor has both a relatively bright response, and a dimmer, very long term decay. This decay allows a form of scan to scan averaging and the response of the bright return forms a pulse to pulse averager which is reasonably effective.

There are two very serious drawbacks to these analogue displays. First, it is not possible to view the screen other than in nearly complete darkness. Thus, the screen is seen by looking into a hood. This makes it difficult to compare the marine radar data with other sensor data, eg SAR. It is also very inconvenient to store the data either as an electronic image, or as a photograph.

The second major drawback of the standard PPI is the inability to have more than one level of brightness. Basically, returns are classed as target or noise by the electronics (under operator control). Targets are 'painted' bright while noise is black so is not seen on the display. In complex ice fields all the ice is painted bright and therefore saturates the display, making it very difficult to get adequate definition of shapes and ice types. It has been shown that a multi-grey scale display can, for the most part, overcome this problem. With an adequate STC and several levels of grey scale in the return, quite complex ice fields can be imaged, in a fashion that is quite compatible with airborne radar imagery. This multi-grey scale may of course also be colour.

4.2.3.3 INTERA's RIDS

INTERA's RIDS has been used in the field for all three operations with the M.V. Arctic. RIDS is a unique piece of equipment since it is able to process, display, and record data from most commercial radars.

The RIDS system can in many ways be considered a prototype ice imaging marine radar system for MIDAS. It incorporates many advanced signal processing algorithms such as pulse to pulse and scan to scan averaging that are useful for imaging ice data. Data are displayed on a high quality colour video monitor and this display can be maintained indefinitely if desired. This bright TV-type display makes it easy to compare the marine radar image with the airborne radar imagery and is useful for keeping track of the ship's progress when used for tactical navigation.

Although RIDS was capable of displaying digital marine radar data and could be used to track the ship's progress on the airborne imagery, there are several problems with it that make it less than ideal for MIDAS. These problems have been studied by INTERA and are basic to any digitally displayed marine radar system which might be considered for MIDAS.

The RIDS system has a 512 by 512 pixel display with four bits assigned to each pixel. There are two image buffers which allow the operator to flicker between two separate images to confirm targets or determine relative motion. The display can be viewed in either black and white or colour. The 512 by 512 display was chosen since it provided a reasonable resolution and is fairly standard for a medium resolution graphics display system. The 4 bit display allows a number of intensity levels to be assigned to the returns from the ice. A single bit display would not be adequate for this purpose.

RIDS also uses a colour to represent these intensity levels and is capable of assigning different radar return intensity levels to different colours on the video display. This assists in classifying the ice imaged by the radar (black and white is also available). When an image with a low signal to noise ratio is being displayed care must be taken so that the noise is not assigned a colour that stands out and saturates the display. A colour lookup table was recently added to the system software so these colour assignments could be changed easily.

The DRI (Digital Radar Interface) built by INTERA for RIDS is capable of interfacing to a total of four radars. The RIDS system may control these radars through the DRI by selecting the radar and the range, or RIDS can be used as a slave display and no direct control. The DRI can interface to a number of radars from different manufacturers. The main problem encountered is obtaining the antenna azimuth information since some manufacturers use resolvers while others use synchros and no standard exists among manufacturers for this repeater interface. If control of the radar from RIDS is required the signals must also be taken from the radar through special wiring. The video and trigger are interfaced with a general analog input buffer consisting of an amplifier with gain and offset as well as inverters to adjust for inverted signals from some radars.

The video is digitized by a six bit analog to digital converter that is capable of digitizing analog signals at rates form dc to 30 Mhz. The azimuth information is digitized to 12 bits providing 1024 radials with actually only 512 radials being used by the RIDS systems.

Since the pulse repetition frequency (PRF) of the radar may change depending on the range selected, the DRI can be set to average 1, 2 or 4 radials to produce 512 radials for each scan. When 4 radials are averaged the PRF from the radar must be greater than 2048 per rotation. This averaging of the radials provides improved signal to noise. The output of the adder buffer contains from 6 to 8 bits of significant information depending on the number of radials averaged. The digitized data consists of 254 range pixels and a 2 byte header containing the antenna position and handshaking signals for radar control from a radial block. The entire scan consists of 512 such radial blocks which is transferred to the RIDS microcomputer through a DMA (direct memory access) interface for further processing and display.

In the RIDS microcomputer the r, theta data are converted to an x, y coordinate system. This is accomplished by adding a delta x and a delta y to the previous x, y coordinate starting from the centre of the screen. The delta x and delta y values are determined by the radial number obtained from the header as well as the amount of rotation required to align the radar display. The data is then normalized to account for the different number of bits which may be available depending on the number of radials averaged.

Next STC correction is applied to compensate for the range dependent effects of the radar return. The STC correction originally consisted of a subtraction from the intensity value (which represented an attenuation on the db scale for a log receiver). This attenuation as a function of range was implemented as a power law function. The operator could select the initial attenuation at near range, and the power to which the function would decay as well as the range at which the attenuation would cease. This was not the optimum STC for the digital ice data; however, and INTERA has implemented a linear multiplication as a function of range to balance the radar display. Figure 31 shows the average return from a radar display of sea ice and open water with no STC applied. Figure 32 shows the effect of applying a linear multiplication to balance the display. The near edge has a gain of one and the far edge has a gain which depends on the image and is selected by the operator. The data then proceeds through a lookup table to assign the colour that is to be displayed. The input of the normalized six to eight bits is converted to the 4 bits available for display.

An analog video processor such as that provided by DECCA's VP1 and VP2 circuits has also been used with some success to provide the required STC correction for ice data. However, these circuits are designed for target detection using a single bit display so the display of ice data is often less than ideal.

The present RIDS system has been criticized for being too slow. This is due to a number of factors present in the original design. First there was insufficient memory available on the PDP 11/23 system at the time of development. As a result, the disk drive is used to store data. Second the complete RIDS software consists of over 300K

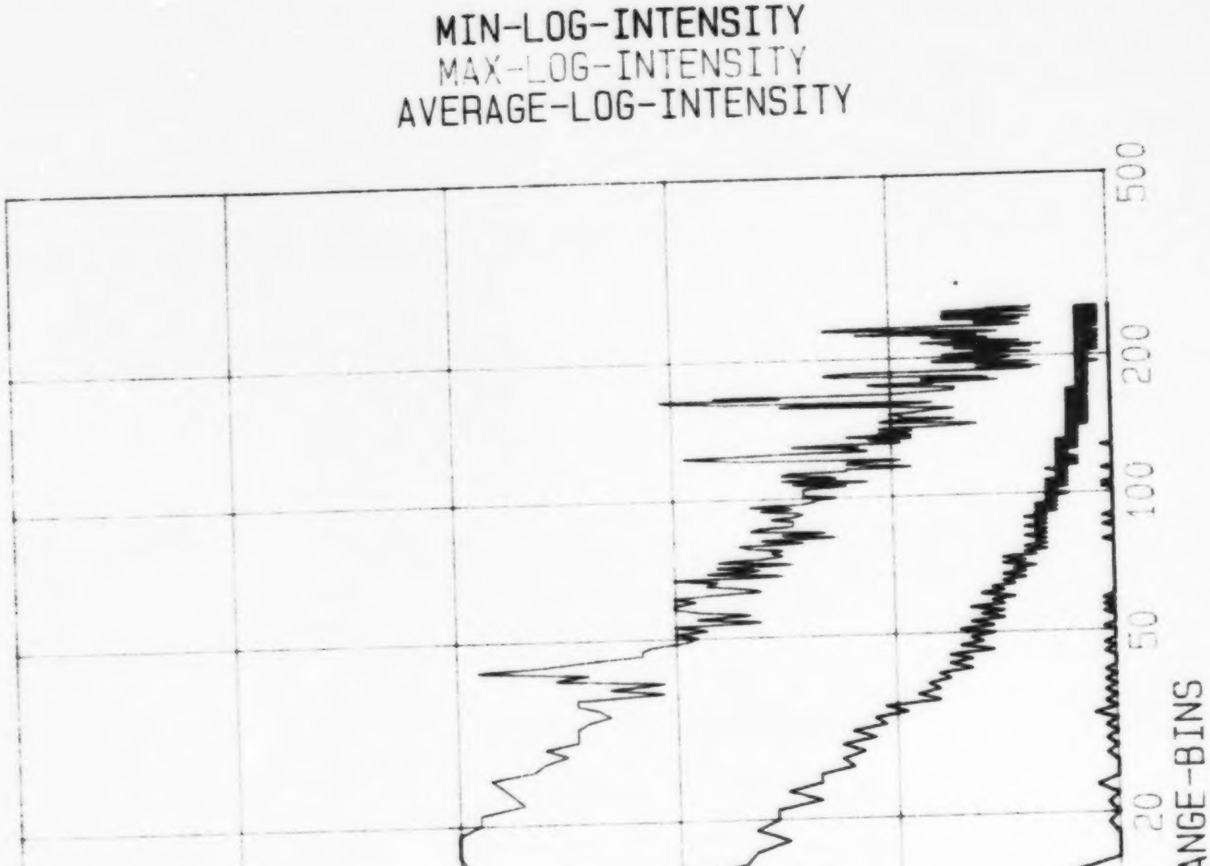


Figure 31. Marine radar image of sea ice with no STC applied.

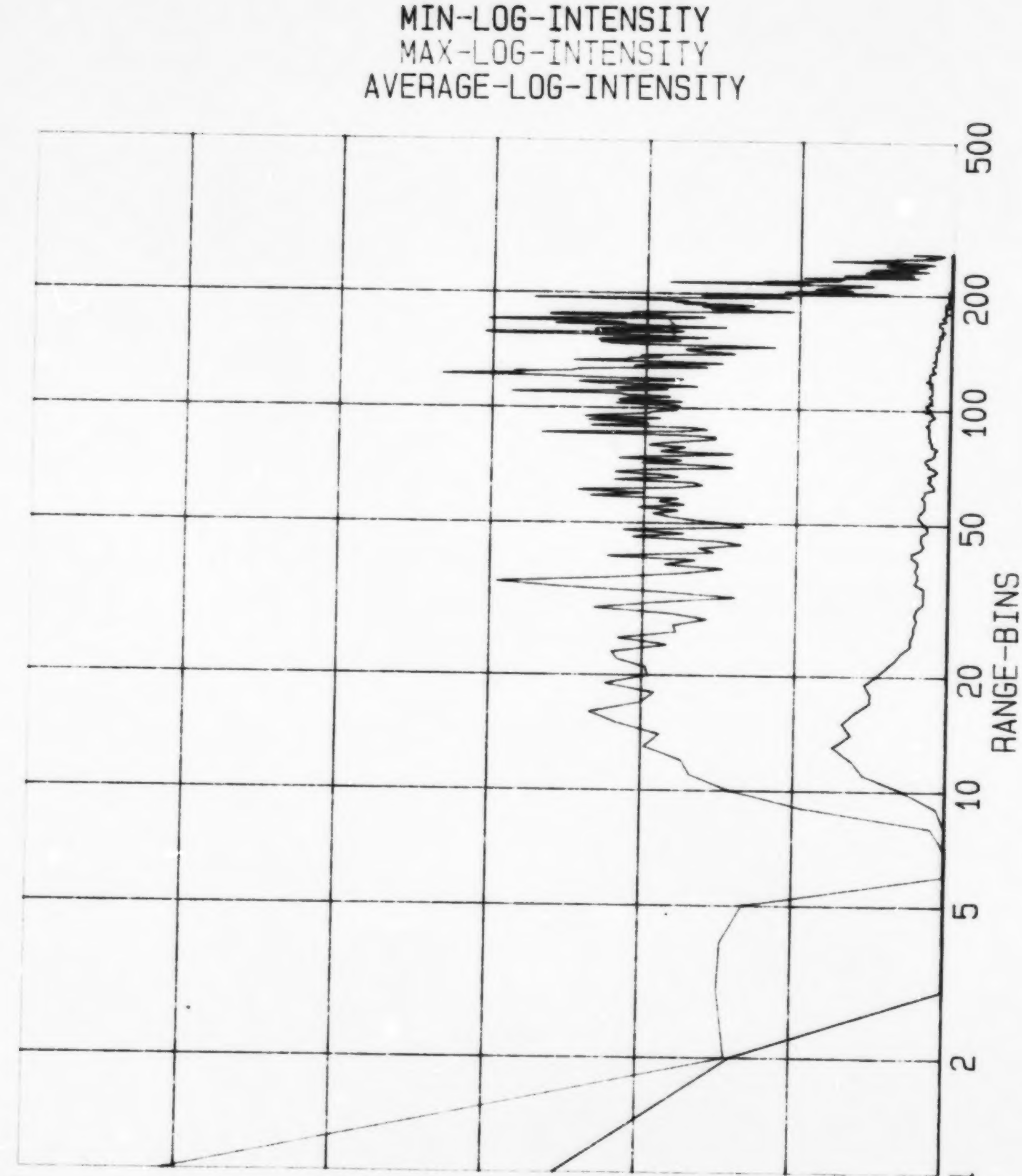


Figure 32. Marine radar image of sea ice with a linear multiplication STC applied to balance the display.

of compiled code which also results in a great deal of disk access. This disk access consumes about thirty to sixty percent of the CPU time. More memory cannot be easily added to the system since much of the software bypasses the operating system.

There are however, several ways that the present system could be speeded up. These include; transferring the software to a faster processor with more memory (eg. the PDP 11-73) and performing more of the operations in main memory or, performing more of the operations like r theta to x,y conversion in hardware. Both of these options are being investigated by INTERA in order to upgrade the current RIDS to make a better ice imaging radar system.

4.2.3.4 Marine Radar System Requirements

There are basically two ways the marine radar aboard a ship navigation in the high Arctic is used; one navigating with, and two navigating without current SAR imagery.

In areas of substantial ice when SAR imagery is available the role of the marine radar is almost always to fill in the information on the SAR mosaics. In particular, given the imperfect knowledge of the ship's location, the aircraft's location when the data were collected, and the shifting ice, finding and keeping track of the position of the ship on the mosaic becomes the major task for the marine radar. Small hazard detection at short range is also a significant task. If the ship is in open water, or in very light ice, and has no need of SAR, then the marine radar becomes, after visual reconnaissance, the prime hazard detection sensor. The signal processing and display requirements are somewhat different from those previously mentioned and return to those of a conventional marine radar.

The task of finding the ship's location on the SAR image while in heavy ice is a major problem. If the SAR image is a standard video display, the marine radar display should sit beside it, and be viewed under similar conditions, and at similar scales; it must also be on a video monitor. It must therefore have a no-fade flicker free presentation. Because the ice can be so very difficult to image in a non-ambiguous fashion, the display needs distinct grey scales. This contrasts with the standard PPI which has effectively one level, as do many of the commercial "bright" displays.

There is a substantial range dependent effect when ice is being imaged. Ice also shows a highly variable target reflectivity and therefore, excellent display and signal processing is required for an ice imaging radar. Such things as the range dependent gain, (STC) and the display grey scale (colour level) are required over a substantial range.

It may be desirable to have the image from the marine radar built up over a period of time, like an airborne SLAR. Since the objective is to obtain an image with which to correlate the SAR image, image extent is of importance. Unlike the target detection case, ice imagery already passed is also of interest. A shipborne "SLAR" could be very useful but requires considerable signal processing and an accurate way to measure the ship's velocity. INTERA has investigated the possibility of producing a prototype system for the M.V. Arctic; however, the ship's current navigational system was less than adequate for this task.

The developments needed for MIDAS are therefore a bright, multi-level display with simple, easily understood controls. The INTERA RIDS has shown that this is indeed the case; however, we are clear that because RIDS is too slow, it would need either to be largely rebuilt or superseded to be practical for MIDAS. The minimum requirements for the marine radar display for MIDAS can be summarized as in Table 11.

---

(1) The system must present marine radar data on a bright TV type display. This display should refresh in real time and allow an individual image to be frozen on the display for any length of time.

(2) The system should be able to interface to any radar without overriding the normal radar controls.

(3) The system should display both north up and ship's head up radar data.

(4) The image should be displayed with the normal radar ranges of 0.75, 1.5, 3, 6, 12, 24 and 48 n miles.

(5) The display must have least 2 bit of video display and should and have a choice of colour or black and white presentation.

(6) It should have the normal radar signal processing such as STC and FTC available.

(7) The user interface should have controls that are similar to or emulate those of a standard radar. It must be easy to use by ship's crew, ice observers, and those familiar with radar systems.

(8) The system must have a standard computer interface so that data can be shared with other computer systems.

(9) The equipment must be reliable and robust and suitable for mounting on the bridge of a ship.

Table 11 Basic requirements for the marine radar display for an ice navigation system.

There have not been any commercial radar systems available in the past which satisfy all of these requirements; however, new digital systems are just now becoming available which may satisfy some. INTERA is currently investigating these systems and evaluating their suitability for Canarctic.

4.3 Future Systems

There are a number of systems currently being developed which will almost certainly play a role in the future MIDAS design. Of prime importance are the European Space Agency SPOT and ERS-1 systems to be used for ocean observations and resource management and the Canadian Radarsat scheduled for launch in 1990. The ERS-1 is scheduled for launch in the period 1986-87 and the sensor payload is expected to include; a synthetic aperature radar (SAR) with 30 metre resolution and 100 km swath, an ocean colour monitor with 10 spectral bands, and an imaging microwave radiometer. Canada's Radarsat is a spaceborne SAR which will operate at 5.3 GHz with an effective ground resoltuion of 25 m. Both of these systems will improve the level of ice information which will be available to a ship operating in the Arctic regions. These systems will have to be carefully studied and the suitability of their data for tactical navigation determined. The main problems forseen are; the limited resolution of the data (25 x 25 m), the fact that the information may not be available to the ship in near real-time due to the time required for processing, and the communications problem of getting a high quality image product to the ship. From our present research it is clear that any interpreted ice charts made from these data sources are not acceptable for tactical navigation tasks.

Passive microwave systems are also showing promise for sea and land ice applications from measurements made by NEMS, SCAMS and the ESMR's or Nimbus 5, 6 and by SMMR on Nimbus 7. Since the satellites have a footprint of 10 - 100 km the resoltuion is relatively course. AES (R. Ramseier) are conducting ongoing studies.

SONAR systems are also now becomming available which could improve the close hazard detection capabilities of ship's in transit and stationery drilling platforms. Canarctic is proceeding with research into these systems under their SINSS program.

5. MIDAS SYSTEM DESIGN

5.1 Design Strategy

The overall objective of the MIDAS program was to develop a reception and analysis facility which is capable of providing both strategic and tactical support for ships in transit and fixed area marine operators in ice infested waters. Specifically the MIDAS contract was aimed at developing a shipborne version of this system.

The shipborne MIDAS design is based on the user requirements that have evolved from the TDC-sponsored field trips on the M.V. Arctic and numerous discussions with commercial marine operators in the Beaufort and other Arctic sea areas. These requirements are summarized in Table 12.

---

(1) MIDAS is a facility that utilizes remotely sensed data for close range hazard detection and for strategic and tactical ice navigation.
(2) This system should make it possible to selectively route a vessel through an ice-field and minimize contact with any ice encountered.
(3) Sources of this remotely sensed data include marine radar, airborne SAR and SLAR and satellite IR/visibles data.
(4) Data must be timely ie. available to a navigating ship in near real-time. It must be available to the operator in an easy to use format.
(5) For strategic planning conventional ice charts are supplemented by IR/visible data from polar orbiting satellites. Airborne radar is also be used in this role.
(6) For tactical and close tactical navigation marine radar is used along with airborne radar. SAR has proven to be ideal for this purpose.

Table 12 Summary of the basic requirements for MIDAS.

One of the key concepts to emerge from this research is that of an "ice navigation chart". Typically, navigators have charts of the worlds oceans; however, what is required for operations in the Arctic is a similar chart showing detailed ice conditions. This requires superior information to what has been available in the past. Features such as old ice and icebergs with sizes of the order of 10 metres should be shown on the chart. Areas of ice rubble, ice build up and ice compression also need to be shown. Because ice conditions change rapidly this information must also be available in real-time.

Airborne radar SAR imagery like that available from INTERA's STAR-1 provides the right image characterisitics and the right level of information to be used as an ice navigation chart. By staging periodic airborne radar missions, geographically annotated airborne radar data can be telemetered to the bridge of a ship in real-time and used for ice navigation. The marine radar provides the means of tracking the position of the ship on the SAR imagery when ice conditions have changed.

Early into the program the design for the system was broken into four main components. These were:

- the downlink SAR/SLAR receiver
- the central image processing workstation
- the marine radar interface
- the external communications interface

These elements were originally thought of as individual pieces of hardware which would be connected by some local area network (Figure 33). Although this has been a useful model it is not clear that this level of integration is required. Also given the present technical "state-of-the-art" of the systems required for input to MIDAS (the marine radar, the real time satellite, and airborne radar) it is impossible to achieve at this time.

For example there is currently no commercially available marine radar system that will meet all the requirements for MIDAS. Although INTERA's RIDS system provides some of the desired functions it is too slow and is unable to do any more signal processing without significant hardware modification. It has also been criticized for being too complex for use by ship's personnel.

The currently available AES ice charts are not always adequate and need to be supplemented by real time satellite imagery. Real time portable satellite receivers however like the one installed on board the MV Arctic are very new and their usefulness for ice navigation is still being evaluated. The system operated by Canarctic has not performed reliably and requires a rather sophisticated user.

The current SAR/SLAR downlink operations are also quite complicated and need to be simplified and automated if possible. The downlink receiver and the user workstation discussed above are closely related and the processing that each requires could be easily be peformed by the same computer (Figure 34). INTERA has recognized the need for such a simplified downlink receiver station that is capable of displaying SAR and SLAR data at high resolution on softcopy devices. In fact, such a system, called "STARVUE" is now being built by INTERA. This system is being designed to automatically receive and store, and interactivley display airborne radar data.

The strategy adopted for the MIDAS design presented here then is based on what is perceived by the investigators as being both realistic and achievable in the near future. The need for MIDAS systems in the field has resulted in this rather more pragmatic approach. To a large extent the design is restricted by the current available commercial products that will make up the system. A current summary of the hardware required MIDAS is given in Table 13. The design must be

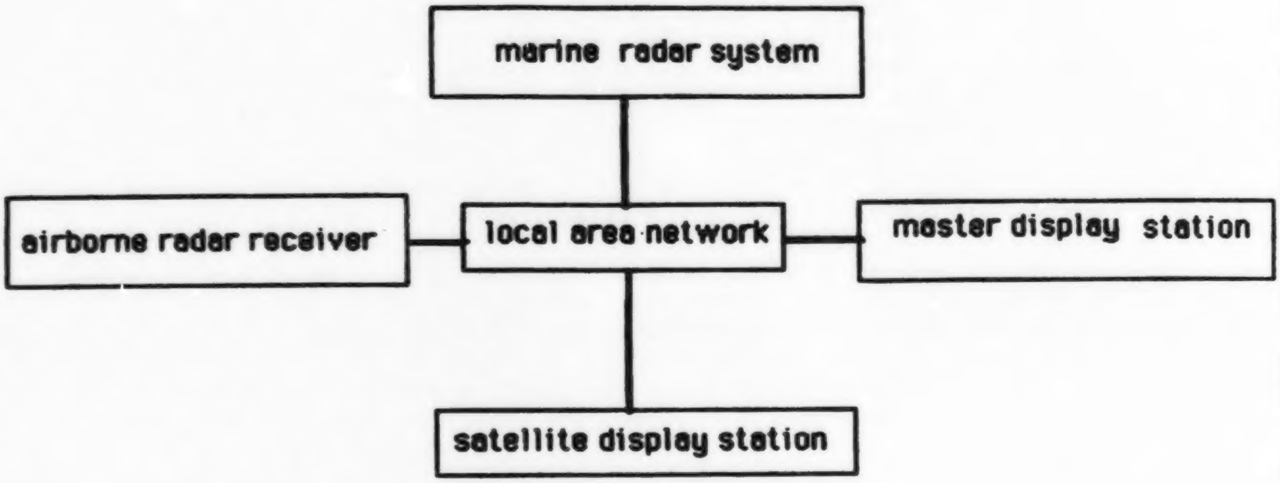

marine radar system
airborne radar receiver
local area network
master display station
satellite display station

Figure 33 Early conceptual desigh for a shipborne MIDAS. All data sources are connected by a local area network under control of the master display station.

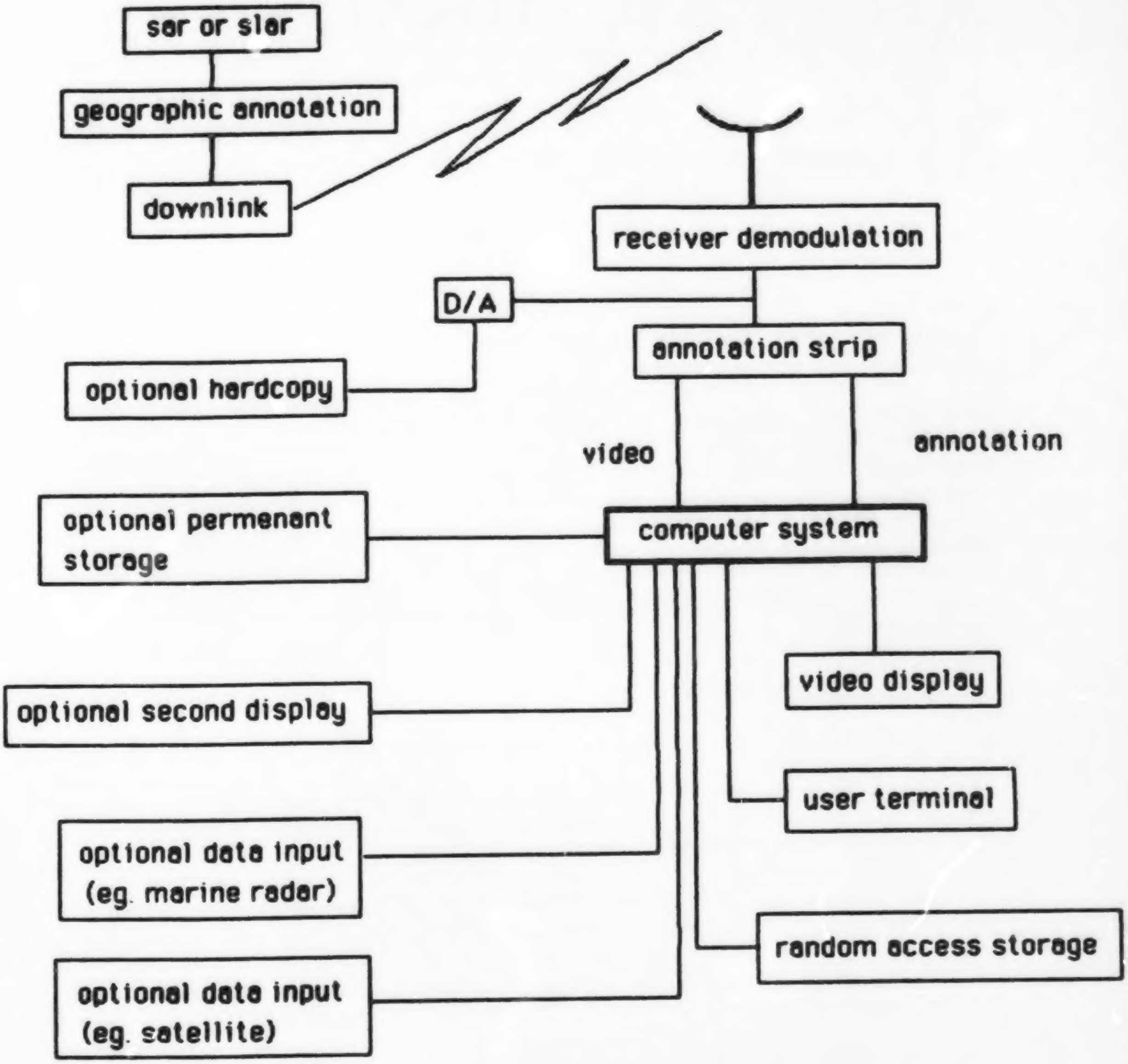

sar or slar
geographic annotation
downlink
receiver demodulation
D/A
annotation strip
optional hardcopy
video
annotation
optional permenant storage
computer system
video display
optional second display
user terminal
optional data input (eg. marine radar)
random access storage
optional data input (eg. satellite)

Figure 34 Base line design of a MIDAS system. Here the downlink receiver and user work station share the same computer system. Such a system should also accept input from data sources like marine radar and satellites. A system incorporating most of these functions, called "STAR-VUE", is now being built by INTERA.

flexible enough so that as new systems and sources of data become available they can be easily integrated into the existing system. We forsee the development of an integrated system consisting of three potentially interlinked systems. The first is the marine radar analysis and display system, the second is an airborne radar data reception storage and display facility, and the third a satellite display system. To proceed at this stage with the final design of an integrated ice management system is seen as premature since the individual components have not been adequately tested as stand alone devices. While the technical specifications for each of the systems is in fact adequate, they have not been tested in actual use by ship's navigating offices.

It is INTERA's recommendation that:

-The individual component systems which will make up MIDAS be separated on the basis of their functionality and operate as independent units for the present time.

-And that integration between these systems proceed slowly and only when the individual systems are fully operational and have been field tested. "Integration" must be more than just exchanging data over some local area network. It must not only allow data to be exchanged but information and allow the operator to interact with this information in a meaningful way. This interaction must therefore be based on careful research. The proposed approach is to build a base system such as that shown in Figure 35. Once this base system is in place in an operational environment an upgrade path can then be implemented.

5.2 System Design

A MIDAS system therefore should consist of:

-A system capable of automatically receiving and storing and interactivley displaying airborne radar data. INTERA's "STARVUE" will provide most of these functions.

-A marine radar display system which is capable of displaying real-time and archived marine radar data on bright TV type displays.

-A system or number of systems capable of receiving conventional ice and weather charts and real time satellite imagery.

-A communications interface between these systems.

In the initial MIDAS design the information communicated between systems will be via a human interpreter. All systems which make up MIDAS though should be open and have a standard computer interface so they are able to exchange data in future. It would be desirable to have considerable commonality in hardware so that each system will be able to take data from the other sensors should a malfunction occur. Figure 36 shows an artist's sketch of a base line MIDAS system. Such a system has been recommended by INTERA for Canarctic's ship the M.V.

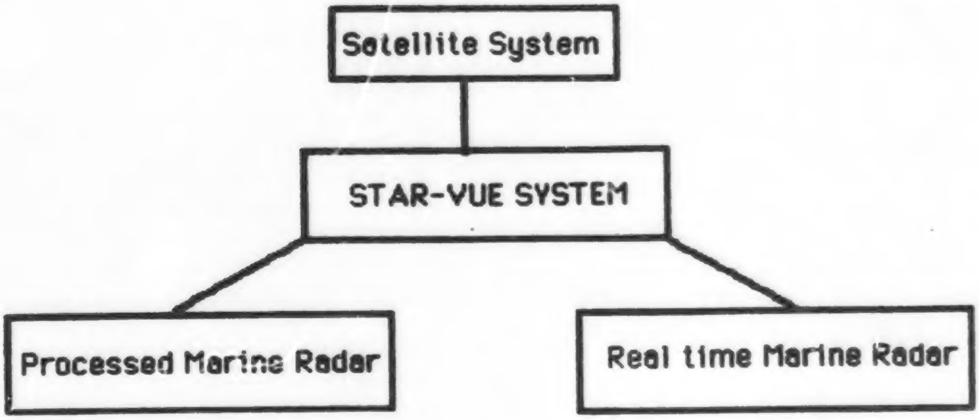

Satellite System
STAR-VUE SYSTEM
Processed Marine Radar
Real time Marine Radar

Figure 35 Recommended MIDAS configuration for a base line system. In this system STAR-VUE has replaced the user workstation and forms the basis for integrating the other individual systems (STAR network). Both a real-time and processed marine radar display system are available for comparison with the airborne imagery.

DATE SOURCE	STATUS
Ice Weather Charts	- available on standard marine facsimilie circuits - timeliness a problem (requires time for interpretation) - communication a problem in the high Arctic
Satellite IR/visible	- lower resolution signals available on VHF from NOAA and other polar orbiting satellites - systems designed to display data need to be field tested
AES SLAR	- uses an expensive large and heavy antenna which requires Electra aircraft - aircraft flown at 7000 ft cannot produce quality imagery - downlink operation complicated - hardcopy product available on UHF downlink; lacks annotation - aircraft cannot respond to user requests for multiple flight lines
INTERA SLAR	- SLAR radar carried in Cessna Conquest aircraft - aircraft flown at 16,000 ft - hardcopy product available on VHF downlink; lacks annotation - aircraft can easily respond to user requests for multiple flight lines - downlink operation complicated
INTERA SAR	- SAR radar carried in Cessna Conquest aircraft - aircraft flown at 30,000 ft - hardcopy available on VHF downlink; lacks annotation - downlink operation complicated - aircraft can easily respond to user requests - provides high resolution (12 m x 12 M) data which can be used for close tactical navigation

Table 13 Current status of the MIDAS hardware.

DATE SOURCE	STATUS
MARINE RADAR	- standard radars designed to detect targets in presence of sea clutter - improved imaging of sea ice accomplished by increasing antenna height, adding low noise amplifier, decreasing beamwidth, etc - bright TV type display required to compare marine radar with airborne radar for navigation - several manufacturers now producing bright TV type displays (Sec. 5.5) - no commercial system specifically designed for imaging ice - RIDS system designed for imaging ice from stationary platform; too slow for moving ship; user interface too complicated for ship's navigating officers

Table 13 continued

Arctic as part of a joint and ongoing research project. While it is known that at least 3 displays, one for satellite, one for SAR/SLAR and one for marine radar are required it is not totally clear what other displays will be needed. The display of the far left of Figure 36 is for a real-time bright TV type radar display. It will normally operate in a slave mode and its main function is to provide a real-time image of the local ice conditions. The second display shown is a special purpose unit such as a RIDS system which is used to display "processed images" and stored marine radar data. The screen update will not necessarily be real-time and will be under much greater operator control. Because of the great flexibility of this system is is anticipated that a computer and terminal will be required for its operation.

The third display is a STAR-VUE system whose primary task is the display of airborne radar data to be used for navigation. STAR-VUE is described in more detail in the following sections.

The fourth display is used for satellite imagery.

There are several requirements for an ice navigation system that must be met. Reliability is one of the prime concerns of the design. This must extend not only to the actual hardware and software placed on a vessel, but to the procedures and equipment used to generate the information used by the ships navigator. Because the safety of a ship and crew could be endangered by a failure of the system, reliability is of upmost importance.

For shipborne equipment this means robust designs which are capable of surviving mechanical shock and a noisy electrical environment typical of an icebreaker. Further, because Arctic going ships are so isolated when under operational conditions, the equipment must have adequate spares, and they should be serviceable by designated ship's officers. There should also be a gracefull decay to the system with key components being duplicated.

To maintain the equipment in optimum condition there must be a proper maintenance schedule. The "maintenance" should also extend to the people operating the equipment. Regualr training and updating sessions should be held, particularly since a vessel may spend substantial portions of its time out of the Arctic. This training should also include regular critical reviews of procedures being used.

The operability of the equipment should be simplified, however, to provide a full understanding of the opportunities presented by this equipment; it is assumed that a substantial training course will be given. It is assumed that none of the navigating officers will have substantial "computers knowledge" so it will not be necessary for them to develop computer programming, or operating systems skills. However, there will be designated personnel who will be tasked with maintenance of the information in the system. Further, all navigating officers should be familiar with the use of the system, so they can use it as

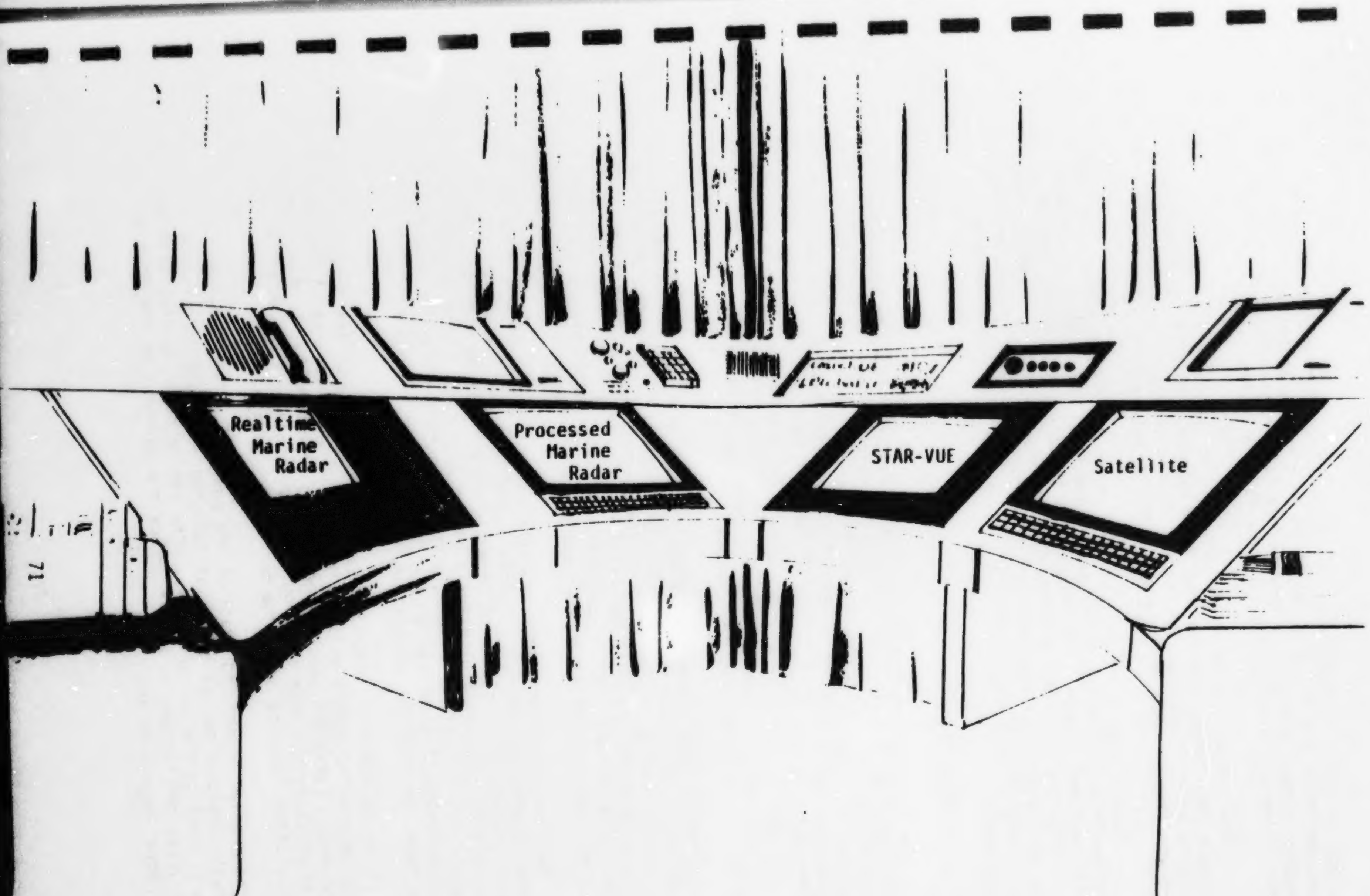

Realtime
Marine
Radar
Processed
Marine
Radar
STAR-VUE
Satellite

Figure 36 A MIDAS system which is suitable for shipbased operation.

a tool in their navigation of the ship. The importance of adequate documentation and training cannot be to strongly emphasized. Since modern systems are usually very nearly 'self documenting' and use of text files and HELP buttons, the emphasis is on training.

The system must be robust and easy to use and should have a minimum requirement for operator intervention. That is, it should only need to be attended when the operator has a need for information and not when the system needs the operator for some action.

The proposed approach for MIDAS is to build base system, and then upgrade this system, based on user interaction. This assures the best possible final system. The base system proposed is seen as consisting of a satellite receiver, a SAR/SLAR receiver, and a bright marine radar display. Where possible, each of these systems should have a back-up, and an upgrade/integration path available (eg. a standard computer interface).

5.3 MIDAS Operation

The currently available ice charts supplemented with real time satellite imagery will provide the first level of strategic information to the MIDAS user. This requires that the user have the equipment necessary to receive these broadcasts and transmissions. Ice charts and weather information are transmitted over both radio and facsimilie systems which are standard marine equipment. Communications are a serious problem in the Arctic though and this can limit the availability of this type of information a real time satellite receiver is therefore also recommended.

Airborne radar imagery provides the user with the next level of support which can be either strategic or tactical. The airborne radar data, (which must be digital), is telemetered to the user via a VHF radio link when the aircraft is within range. This information can be the real time imagery that is currently being collected by the aircraft or can be imagery recorded earlier and stored on magnetic media.

The airborne radar imagery is received and stored automaticaly by a system located on the ship. INTERA's STARVUE is such a system and any area imaged can be displayed on a high quality video monitor. The system must be capable of displaying an airborne radar image of a large area which can be used for strategic route planning as well as a high resolution image of a smaller area which can be used along with the marine radar for tactical navigation.

It is assumed that after a reasonable short search the ship's position on the SAR mosaic will be found. The geo-reference on the SAR imagery should limit the search area to less than 5 n mi. This will be achieved by using the roam and zoom features of STAR-VUE to select a high resolution image to match the marine radar image.

The problem of keeping track of the position of the ship is also greatly reduced by using the latitude and longitude information that is present on the airborne data. The marine radar is displayed on another video monitor and is used to track the movement of the ship on the airborne image display.

Experience with the MV Arctic has shown that the marine radar is the key to keeping track of the position of the ship in the airborne imagery and providing steering information to the ship. This is true even after several hours have past and the ice conditions have changed. Both real-time and suitably "processed" radar imagery may be required for these tasks. The image to image correlation is not by machine but by a human observer for the first development phase of MIDAS. By using a selected number of stored marine radar images it will also be possible for the operator to go back in time and retrace the ship's location if for example the operator becomes lost. With a shifting and moving ice pack this "second look" may be a very useful feature.

5.4 The Airborne Radar Receiver and User Workstation

The understanding gained by studying the way airborne radar data are currently received, displayed and then used for tactical navigation has resulted in a new product being developed by INTERA. This product, called "STARVUE" is an interactive system for receiving, storing and displaying airborne radar, and other image data on softcopy devices.

There are several advantages to the use of softcopy display. These include:

-The system can be built largely of easy to use software and new features can be added with a minimum of effort.

-A higher resolution image can be displayed using a a good quality video monitor with very little effort.

-The cost of softcopy display devices is significantly cheaper than the currently available hardcopy displays.

INTERA's STARVUE is basically a downlink receiver and data analysis workstation. It will consist of a kernel of functions structured such that other functions can be easily added to it later. Although it will not perform all the functions of a ship's ice navigation system it represents a significant improvement over the current hardcopy system and is described here in detail. Those functions which could be added to STAR-VUE to make it a complete ice navigation system are also described.

5.4.1 STAR-VUE

5.4.1.1 General Description

STARVUE is a relatively low cost system that will allow users to receive, store and display real-time digital SAR and SLAR data. It is a microcomputer-based system which serves as both a receiver and user workstation. Geographically annotated airborne radar data that are telemetered from the aircraft are automatically received and stored on a random access media (e.g., magnetic disk) by the system.

The received data are used to form image strips which represent the area covered by the individual flights. Since it is not possible to display an entire flight line image in full resolution on a video monitor, the images are viewed through an adjustable window. A window surrounds the area of interest on a single image the user wishes to have displayed. Changing window size changes the image magnification. The window may be chosen such that a whole flight line image fits on the video screen at a reduced resolution or such that only part of the image is visible at a higher resolution.

Thus the user can scan over a very large radar image at full resolution by keeping the window size small and varying its position over the whole radar flight line. The advantage of windowing is that the user can specify directly the rectangle of interest he wishes to see displayed. Since it may be desirable to view more than one image at a time, or a single image at more than one magnification, the user can define "viewports" for the display. A viewport defines the rectangle on the video screen or screens where the contents of the window are displayed. For the case of a ship navigating in ice at least two viewports are required; one viewport would display an overview image - perhaps an entire flight line while the other viewport would display a smaller area of the same image presented at a higher resolution. Figure 37 is a prototype STAR-VUE display that was developed on a MASSCOMP computer. The color processor utilizes a 19 inch monitor with 832 x 600 pixel resoltuion. The image on the left is an overview image of an entire flight line. The image on the right is a full resolution image that has been annotated with latitude and longitude information. The soft buttons at the bottom of the display are used for control purposes.

A viewing transform converts the contents of the window which are defined in the latitude and longitude coordinate system of the radar image to the proper screen coordinates.

5.4.1.2 The User Interface

The user interface describes the interaction between the human and the machine. The STARVUE uses multilevel menus for command and operation selection.

Programmed function keys or graphical icons are used to traverse the menus which display the full range of options avialable to the user. For those tasks which require graphical interaction, like moving a window around a flight line image, graphical input is via a mouse or joystick which controls a stylus displayed on a video monitor.

The need to optimize the use of screen space is achieved through the use of windows; retangular regions of the screen whose positions and dimensions are set by the user. These windows may be placed on a single screen or distributed over several screens and include:

- Image windows used for displaying SAR data
- A graphics window for flight planning etc.
- An operation i.e., text window used for displaying the menu system
- A process or status window use for error messages, prompts etc.

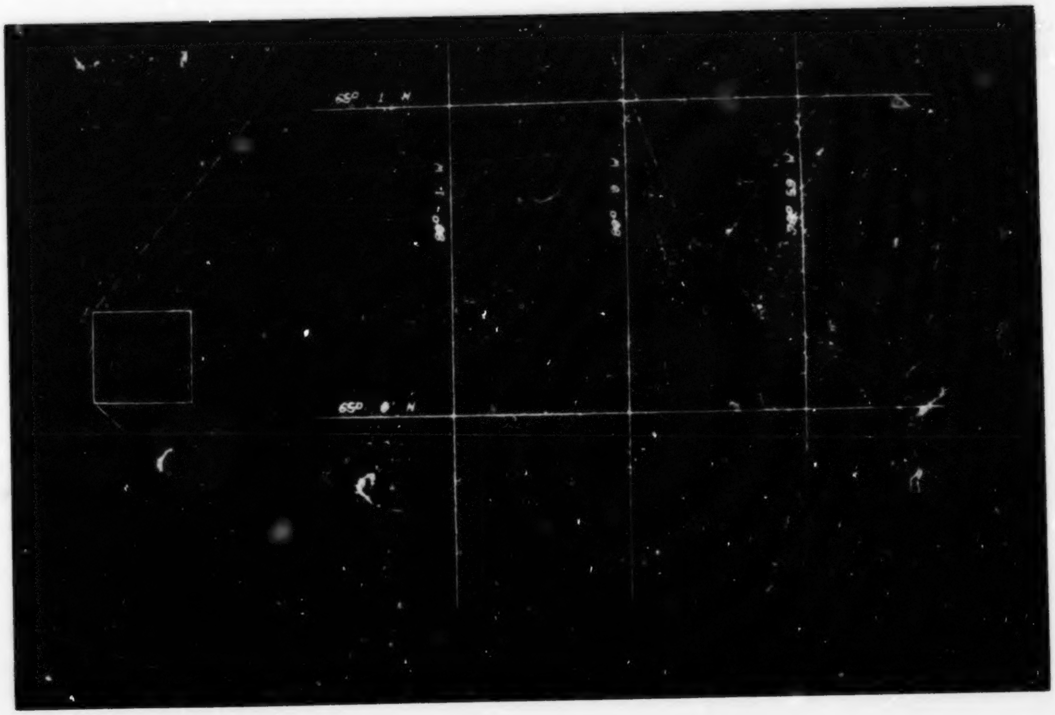


Figure 37 Prototype STAR-VUE display on a high resolution monitor.

Both text and process windows will be resident on the display screen of the host computer system. The system will also include an on-line help facility.

5.4.1.3 System Functions

The basic functions to be performed by the system form the root level of the menu system which is presented to the user. These functions are:

- Image display
- Flight request planning
- Data Management
- System function and training

5.4.1.3.1 Image Display

This function allows the user to display SAR imagery on a video monitor. The main functions offered under this option are:

-Display Catalogue: The operator is presented with a graphical, geographical presentation of the flight lines in storage at their current geographic location on a map. A simple list of flight lines can also be requested.

-Select a Flightline Image: The operator can select any one of the stored flight lines, for display by moving a window cursor on to the graphical presentation of the flight line images. The window cursor movement is controlled with the mouse.

-Display Imagery: Using the currently selected flight line, the operator selects his area of interest with the window cursor. The cursor is a box whose size determines the amount of the image to be displayed. The operator can see both the location of the cursor on the map flight line, and the location of its centre (in lat/long) printed on the status window. Should the operator wish to select by lat/long, the position of the cursor will be available on the screen.

Provision will be made to allow the user to define a number of display viewports and the place in each viewport either different flight line images, or similar images with different scaling.

A roam option will allow the operator to move his window cursor about a low resolution image displayed on one viewport and display a second high resolution image of the window contents on another viewport.

A latitude and longitude grid will be available on the imagery and can be turned on or off if requested.

5.4.1.3.2 Flight Request Planning

One of the functions performed by the system will be flight line planning. This will allow the user to interactively determine flight coordinates from a digital map displayed by the system. Having the computer system calculate the flight line assures correctness and also serves a secondary function of managing the task of data storage. The following options would be present under the flight planning menu selection.

Option 1. Show Map
2. Selected Radar Type
3. Specify Flight Lines
4. Show Donwlink Range

-Show Map: The operator is presented with a choice of general areas of interest.

- North America
- Europe
- Etc.

Having made a selection the map of this area will be presented. When the map of the appropriate area is presented, the operator is allowed to roam and zoom on the map with the window cursor to establish the exact presentation required for the creation of flight lines.

-Select Radar Type: The operator is requested to select one radar from the following list:

- SAR/STAR-1 wide swath
- SAR/STAR-1 narrow swath
- INTERA SLAR 50 km 1 side
- INTERA SLAR 25 km 1 side
- INTERA SLAR 50 km 2 sides
- INTERA SLAR 25 km 2 sides
- AES SLAR 50 km 2 sides

-Specify Flight Lines: Using the map selected in (Select Radar Type) the operator can select flight lines for the radar selected in (Specify Flight Lines). This is done by interactive graphics. The operator selects a location for the "start" of the line, then a "stop". The line can then be moved or changed. Co-ordinates for the cursor can be obtained to verify the location. The operands are:

1. START point
2. STOP point
3. Move line
4. Change Start point
5. Change Stop point
6. Check co-ordinates of cursor
7. Accept line
8. Next line
9. Review requests
10. Remove a line
11. Selection complete

Upon completion of the line selection, the system will exit to a display showing the map, with requested flight lines and a circle of 200 n mile radius. This represents the maximum normal range of a downlink. The operator can then;

1. Accept lines as shown
2. Move downlink coverage circle
3. Review flight line requests

Option 1 is obvious, and the system proceeds to the next stage. Option 2 allows the operator to move tha centre location of the 200 n mile circle, with the actual lat/long being printed out on the screen. Option 3 returns to the previous section.

The next thing that is required is to show the operator both the amount of flying requested and the storage requirements. This wil be shown as following:

Flight Line Requested	xxxx km
	xxxx n miles
Data Storage Requested	xxxx blocks
There are currently free	xx blocks in use
of a total of	xxxx blocks required

If the operator has selected more data than can be stored on the system storage, he will be notified he must mount a tape. Otherwise he will be allowed to review the data. Normally storage is adequate, but data must be over written. He will be offered these options.

- Show Existing Files
- Archive Existing Data (tape)
- Prioritize Overwrite
- Selection Complete
- Review Flight Request

Data existing in the files will be shown along with its age (time of collection). The operator can chose to archive data to tape, if required. Alternately, the existing data can be overwritten, in a user selected priority. Any file not priortized will be assumed protected. The system will prompt for prioritizing. Under no circumstances will the system automatically overwrite data files.

Upon completion, the operator will receive a print out of the flight lines requested, which can then be forwarded to the aircraft by whatever means selected.

5.4.1.3.3 Data Management

This series of options allows the user to deal with data i.e., flight line image management. The options to be included here include:

- Show the flight lines on storage and those requested
- Shift data between storage media
- Remove or selectively overwrite files on disk

5.4.1.3.4 System Function and Training

These options will allow for system installation, maintenance and diagnostics. The installation procedure would include viewport and window selection. In this way "STARVUE" can be tailored to an individual users requirements. A user help facility and training session will also be presented to quickly familiarize new users with the system.

5.5 Ice Navigation Workstation

STAR-VUE is a commercial product being built by INTERA and aimed at a large and diverse market for SAR and SLAR imagery. As such it is not being built strictly for ice navigation even though it performs the majority of the functions required and is the recommended choice for a MIDAS system. There are several functions which could be added to the sytem to make it a more complete ice navigation workstation. STAR-VUE is designed so that these functions can easily be added to the software base. The system should allow an operator to interactively select waypoints, as appropriate, on the image for route planning. It should be possible to select these points using the absolute latitude and longtitude information contained in the imagery or relative to the ice location. Having drawn the route on the display the operator must be able to store the data and have these waypoints printed out if desired. These could then be transmitted via telex to escort vessels on the the ship's main office.

Close tractical navigation requires that the operator locate the position of the ship on the SAR mosaic, with the marine radar. As "fixes" are made the ship's track should be recorded as a line drawn on the video display, with time ticks at the operator noted points. These time ticks serve the dual purpose of providing a record of the ships track for posterity, and to be "retraced" should the ships location be "lost".

In shifting pack ice it is often the shapes of large floes that are used to match the SAR and marine images. It is assumed that some type of "form outlining" can be done using one bit of the SAR or marine radar displays and that this outline transferred from one display to the other to allow complex shapes to be compared. A final feature of the ice navigation system that is as yet very poorly developed is the speed in ice measurement. Ships logs are generally very poor in ice and other types of speed measuring instruments such a speed radars are required. Accurate ships speed and heading would simplify the ice recognition and tracking tasks.

At this time it is difficult to know what other features may be desirable for the ice navigation workstation. This will have to await further field trials with the above recommended equipment.

5.6 The Marine Radar Display System

The requirements for the marine radar system have been outlined previously. There it was indicated that no commercial systems have been available to date that will meet all the requirements for MIDAS. Several radar manufacturers however are now marketing low end radar systems with bright TV type displays. A list of several products now available is given in Table 14. The table summarizes the performance of these systems along with INTERAs RIDS.

	RESOLUTION				RELIABILITY	
		Geometric			Physical	
	Radiometric	Range	Azimuth	Real Time	Ruggedness	Service
DECCA	1 bit	35 m min.	N/A	yes	N/A	Limited new product
Furuno	2 bits (4 levels)	N/A	N/A	yes	N/A	N/A
JRC 1 2 3	2 bits (4 levels)	28 m min.	1250 sample	yes	good	Good 50 sold
RIDS	8 bits (16 levels) Displayed	23 m min.	512	no	R & D	In-house

Table 14 A summary of the bright radar displays currently available from several manufacturers.

Such systems like those manufactured by the Japan Radio Corporation may be suitable for a base line MIDAS system provided they can interface to standard marine radar systems and that they have sufficient processing power to present a high quality display of ice data. The attraction of using this type of display for the marine component to MIDAS is that it is a standard off the shelf product. Secondly the user interface to this type of system is already in place - it looks and acts like a conventional marine radar so should not pose any learning problems for ship's personnel. These systems are able to display radar data in real-time which is required for close tactical navigation and hazard avoidance.

INTERA is now researching these systems under a Canarctic contract in the hope that one will prove to be suitable for the real-time display portion of the marine radar system.

While these "repeater" radar displays are able to process and display data in real-time it is not clear that the resoltuion of these systems will be adequate for displaying the finest resolution data. They also lack many of the features which seem to be very desirable for the marine radar display system. INTERA's RIDS system could be upgraded for this role however. RIDS performs most of the features required for MIDAS. It also provides an image storage capability which is useful for the short term, when it is possible to become lost, and for the longer term, when it is essential to record data for later analyses. The main problems with the RIDS system however are the fact that it is too slow and the user interface too complicated. Both of these problems could easily be remedied by upgrading the hardware and software. For the present INTERA has recommended to Canarctic that a commercial real-time repeater display be purchased and installed on their ship and that a RIDS system also be installed at the same time. The repeater system will be used for making real-time decisions while RIDS will be upgraded and provide "enhanced" imagery as well as the capability of storing these data. This strategy should also be adapted by MIDAS until new systems become available or until existing systems are upgraded to satisfy the user requirements.

5.7 Satellite Receiver Station

It has been demonstrated that a variety of services including meteorological summaries, ice charts, ocean current analyses, images and oceanographic products are required for strategic route planning and marine operations in the Arctic. The majority of these data products are available from government agenices like Atmospherc Environment Services (AES) and are distributed on a regular basis. Weather summaries and bulletins are available on teletype. Meteorological and oceanographic products may consist of raw numeric data, charts, or gridded analyses and are available on facsimilie (FAX) devices. In addition many image services are also transmitted on standard FAX circuits. These include data received by the SMS/GOES series of geostationery satellites, weather facsimilies (WEFA) and TIROS-N/NOAA facsimilie displays.

Research is being conducted by operators like Canarctic to evaluate the quality and availability of these products for ice navigation. Much more research is required though before it can be determined which of these services are essential. It should be noted that both FAX and teletype are already standard marine equipment on most ocean going ships.

Because of the communication problems encountered by the MV Arctic while operating in the Atlantic and in the high Arctic more direct real time products are also required. The NOAA polar orbitting statellite provides a direct readout service by broadcasting AVHRR and TOVS data to ground stations around the world. AVHRR data is broadcast as both low resoltuion (4 km) Automatic Picture Transmission (APT) and a High Resolution (1 km) Picture Transmission (HRPT).

Canarctic receives the APT signals on a VHF receiver built by Muirhead System Ltd. The station receives two or more broadcasts per day depending on the latitutde of the ship. It provides useful information when it is operational and when the imagery is not obscured by cloud. Unfortunately equipment problems have limited the up-time of the system so it is difficult to draw many conclusions about its final role in the MIDAS program. The satellite system is relatively inexpensive however since it operates on VHF and there is no cost for receiving imagery. This makes it attractive. However, it may be desirable to have a higher resolution product which would mean installing an S-band receiver to receive the HRPT transmissions. It may also be desirable to have georeferenced imagery or at least the specific orbital reference information of the satellites. More research, in an operational environment, is required to answer these questions. Canarctic is ideally placed to conduct this research and is in fact devoting resources to this study. The current receiver installed on the MV Arctic appears to be a valuable tool and should be considered as an important part of the MIDAS system. INTERA recommends that research continue in this area to fully define the equipment, personnel, facilities and data required for strategic planning for these marine operators.

6. CONCLUSIONS AND RECOMMENDATIONS

This report has presented a detailed requirements document and functional specification for MIDAS. A MIDAS system design has also been described. MIDAS is composed of a number of individual systems which are used to display the remotely sensed data required for ice navigation. These include a marine radar display system, an airborne radar display system and a visual/IR satellite display system. At this time it is not clear what level of integration will be required among the systems to improve the ice navigation tasks. This integration must be based on future research. It is therefore recommended that these systems be operated individually and that no integration take place until each system has met the users requirements and been fully tested in a field environment.

The major input to the MIDAS design has come from an examination of commercial shipping operators in the Canadian Arctic. The M.V. Arctic has been the prime source of information for these investigations. It has been demonstrated that the high quality ice information provided by a MIDAS system can greatly improve the operations of ice breaking cargo carriers. This results in faster voyages using less fuel and subjecting the ships to much less potential for loss of revenue due to actual damage.

It is therefore recommended that other operators and operational areas be investigated and used to test out the applicability of MIDAS system to these operations. A prime candidate for such a study would be, for example, the Canadian Coast Guard icebreakers operating in the Gulf of the St. Lawrence.

Airborne Radar System

It has been demonstrated that SAR and SLAR data can be used for both strategic and tactical navigation by ships operating in an ice environment when these data are available in near real-time. The currently available real-time SAR and SLAR hardcopy products however are not ideal for the task of ice navigation since they lack geographic annotation and do not allow the data to be displayed at full resoltuion. The downlink operation is also guite complicated. INTERA has recommended that a system like STAR-VUE perform the role of an airborne radar workstation since it does not have these inherent limitations. STAR-VUE however has not been designed as a complete ice navigation workstation and more research is required to define the equipment, procedures, and functions required for such a system. It is recommended that an ice navigation workstation like that described in this report which uses STAR-VUE as a base system be built and field tested. It is also recommended that human factors personnel participate in this system's development. They should review the design, help determine the knowledge that will be required to perform various tasks, and influence decisions in areas such as labelling, control selection, display design, and workspace layout.

The results of this study have shown that 4 bit SAR imagery with a 12 m by 12 m ground resolution is adequate for almost all ice navigation applications. However more research is required to determine the optimum parameters for the radar imagery.

Such factors as the attenuation, range dependent gain, and dynamic range need to be clearly specified for a variety of ice conditions. Because the radiometric fidelity of SAR imagery is so good it has been readily accepted by navigators since it is easily used for ice navigation. More research is required however to determine if image processing and filtering can further improve the information content of the resultant display. Techniques for edge detection, histogram equilization, spatial and textural filtering need to be examined. Artifical Intelligence techniques of pattern recognition should also be considered in attempts to automatically classify ice types. This would be very useful for navigators.

The problem of the image to image correlation between the airborne radar and the marine radar also needs to be more fully investigated. This report has indicated that this correlation can be done manually if the images are presented at the same scale and have the same orientation. It may be possible to improve this by transferring images or outlines of images from one display to another or to flicker between images on the same display. It may also be possible to develop automatic techniques of doing this correlation based on pattern recognition.

Marine Radar System

There is no commercially available marine radar system that has been designed as an "ice imaging radar" however several manufacturers are now marketing low end radar systems with bright TV type displays. These systems provide many of the functions required by the MIDAS user and as such are very attractive. Such systems need to carefully evaluated through and their suitability for "ice imaging" determined.

INTERA's RIDS system is able to perform many of the signal processing tasks required to enhance the display of ice data on a bright TV type monitor. The results to date have been very encouraging but the system lacks the power to perform operations in real-time. INTERA recommends that research continue on the RIDS system to speed up the processing and quality of the display. Functions which could easily be improved include; performing scan to scan averaging in real-time, doing more pulse to pulse averaging on the DRI, performing r, theta to x-y coversion in real-time and incorporating analogue STC and FTC circuits into the system. It may also be desirable to modify the system software to overlay the imagery from more than one radar on a single display. The RIDS user interface also requires modification if it is to be recommended for MIDAS.

Satellite Receiver Stations

Communications are a serious problem in the Arctic and these can restrict the availability of ice charts, images and other meteorological products. INTERA recommends a complete study of this communication problem and an examination of other means of relaying data eg. via other commercial satellite or systems. INTERA also recommends a complete study of systems like Muirheads which are now available and also capable of receiving APT data from polar orbiting satellites.

Future Research

The MIDAS project has generated a detailed requirements document and functional specification for a shipborne ice nuvigation system. The core of this system is the marine radar display system and the airborne radar display/user workstation. These two systems; however, still require future research and development if they are to serve in this critical role. The airborne radar receiver/user workstation must be expanded to perform the tasks of ice navigation; the marine radar must be developed to an advanced stage to be used for ice imaging. It is hoped the further research will bring about this required development.

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